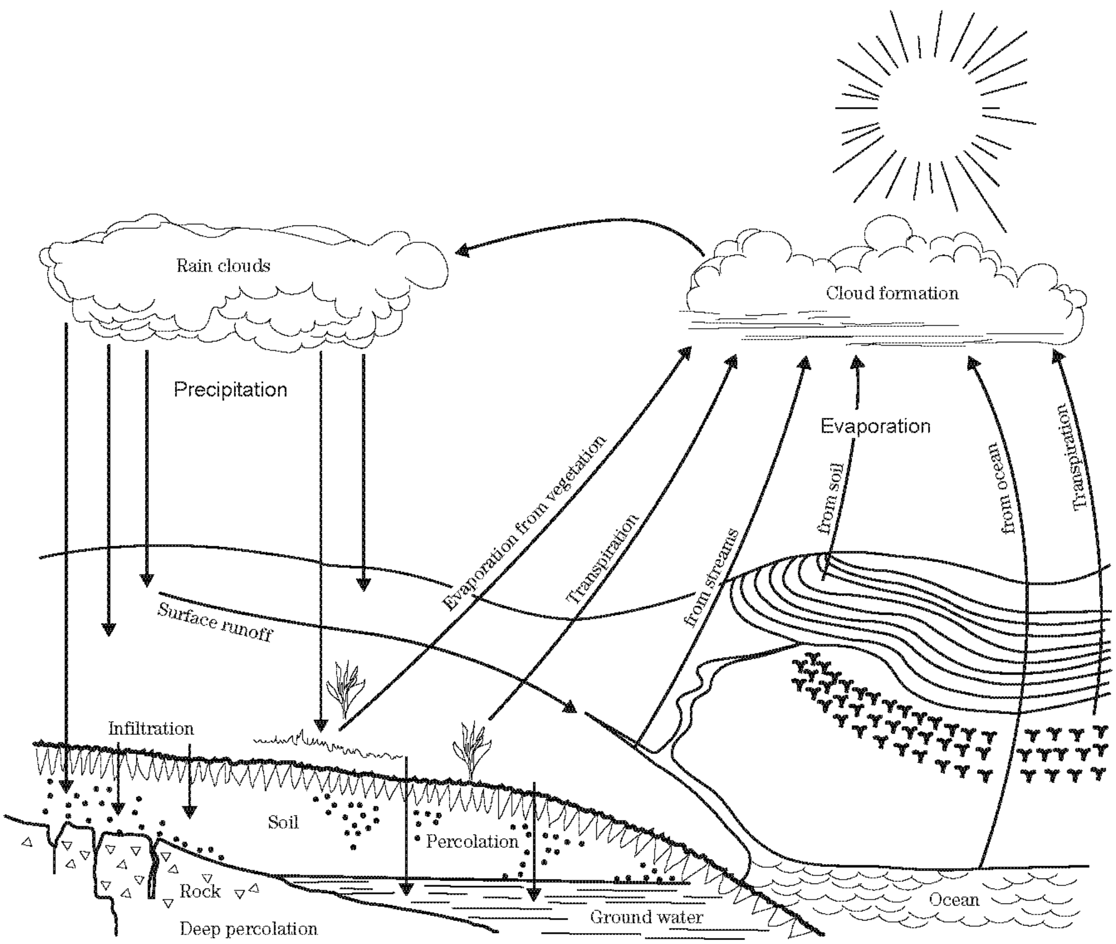
United States Department of Agriculture

Natural Resources Conservation Service

Part 630 Hydrology
National Engineering Handbook

Chapter 4 Storm Rainfall Depth and Distribution



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630.0400 General

A. Acknowledgements

(1) **Victor Mockus** (retired) originally prepared Chapter 4, "Storm Rainfall Depth and Distribution," in 1964. The Soil Conservation Service (SCS) updated chapter 4 with minor revisions in 1969 and NRCS updated chapter 4 with major revisions in 1993.

(2) **William H. Merkel** (retired), **Helen Fox Moody** (retired), and **Quan D. Quan**, Hydraulic Engineer, NRCS, Beltsville, MD, prepared this version of chapter 4 under the guidance of **Claudia C. Hoeft**, National Hydraulic Engineer, NRCS, Washington, DC. Numerous NRCS engineers in the States and centers also provided reviews, including **Ruth Book** (Champaign, IL); **Geoffrey Cerrelli** (retired, Harrisburg, PA); **Terry Costner** (retired, Temple, TX); **Jon Fripp** (National Design, Construction, and Soil Mechanics Center (NDCSMC), Fort Worth, TX); **John McClung** (retired, Little Rock, AR); **Tim Ridley** (Morgantown, WV); **Ben Smith** (Tolland, CT); **Sonia Jacobsen** (retired, St. Paul, MN) and **Karl Visser** (NDCSMC, Fort Worth, TX). **Wendy Pierce**, illustrator, and **Suzi Self** (retired, Ft. Worth, TX), National Center of Excellence, NRCS, Fort Worth, TX, provided much of the illustration and editing services.

B. Introduction

(1) NRCS Title 210, National Engineering Handbook, Part 630, Chapter 4 (210-NEH-630-4), applies to specific rain events and their analyses as well as monthly and annual rainfall. Chapter 4 also provides a brief account of the sources, variability, and preparation of storm rainfall or precipitation data. This chapter is used with 210-NEH-630-10, "Estimation of Direct Runoff from Storm Rainfall" (NRCS 2004); 210-NEH-630-16, "Hydrographs" (NRCS 2007); 210-NEH-650-2, "Estimating Runoff and Peak Discharges" (NRCS 1993); and 210-NEH-630-21, "Design Hydrographs" (NRCS 2019b) for estimating the runoff volumes and peak discharges needed to size conservation and water control structures. Probable maximum precipitation (PMP) is described in 210-NEH-630-21, (NRCS 2109b), and Technical Release (TR) No. 60, "Earth Dams and Reservoirs" (NRCS 2019a). Various National Oceanic and Atmospheric Administration (NOAA) documents cover areal reduction of rainfall.

(2) Storm rainfall depth is the quantity of rain falling within a storm of a specific duration distributed uniformly over the watershed area. Rainfall depth is expressed in inches when using English units, and millimeters when using the International System of physical units (SI). Rainfall distribution is the quantity of rain falling in successive time increments of the total storm duration. In this chapter, the cumulative fraction of rain falling at successive times up to the storm duration is used to develop the rainfall distribution. The rainfall distribution begins at a value of zero at the beginning of the storm and ends at a value of 1.0.

(3) NRCS hydrologic models WinTR-20 (NRCS 2010a), WinTR-55 (NRCS 2009a), and SITES (NRCS 2005), referenced at various places in this chapter, utilize storm rainfall depth and rainfall distribution to calculate runoff hydrographs. Principles described in this chapter are useful in many hydrologic computer models of Federal, State, local governments, universities, consulting engineers, and others that use a distribution of rainfall throughout a storm. The rainfall distribution concept applies to a design or synthetic storm or to an actual storm and is described in this chapter. Standard use of these hydrologic models assumes rain falls on the watershed uniformly with respect to spatial and temporal distributions. This

represents a standard use of the hydrologic models, however, WinTR-20 (NRCS 2010a) and SITES (NRCS 2005) may also be used to analyze watersheds with nonuniform spatial and temporal distributions.

(4) The examples illustrate analyses of storm depths and temporal distributions using calculators, spreadsheets, computer programs, and geographic information systems (GISs). Values calculated by these methods may differ slightly based upon the method used. Numerical precision is a function of the number of significant digits and the algorithms used in data processing, so some differences in numbers may also be found when the examples are checked by other means.

(5) This document provides website addresses for some data sources and reference items. If a given web address has expired, the user can usually find the information needed with a search engine and appropriate keywords.

630.0401 Sources of Data

A. Hydrometeorological data are important elements of NRCS planning, design, and operation of water-related structures and systems. There are several data sources for hydrometeorological data, including the—

(1) NRCS National Water and Climate Center (NWCC).
(2) U.S. Geological Survey (USGS).
(3) National Oceanic and Atmospheric Administration (NOAA).
(4) National Weather Service (NWS).
(5) NOAA National Center for Environmental Information (NCEI), formerly the National Climatic Data Center (NCDC).
(6) Six regional climate centers (RCCs).
(7) State climatologist.
(8) Agricultural Research Service (ARS).
(9) Forest Service (FS).
(10) Other Federal, State, and local agencies with planning responsibilities for water related projects, operational responsibilities, or both.

B. Rainfall data and related statistical analyses used to design NRCS engineering measures are generally those amounts measured and published by the NOAA and NWS. The choice of NWS data is due to its availability, length of record, and consistency on a national basis. Numerous other organizations publish data, research reports, and analyses. Use of data from other sources is justified if the data are more recent or more applicable to a specific project purpose, location, or both. Rainfall data sources should be documented and justification for use of non-NWS data should be provided.

C. Although collection of hydrometeorological data is not described in this chapter, for those interested in data collection, a comprehensive account and bibliography of rain gage designs, installations, and measurement research is available through the Citizen Weather Observer program website at http://www.wxqa.com/resources.html (CWOP 2014), and by Kurtyka (1953), NOAA (1995), NOAA and the Office of the Federal Coordinator for Meteorological Services and Supporting Research (NOAA and OFCM 1995), NWS (1989, 2015a), and others. Vasquez (1998) gives an overview of general weather station operation. Gages used in the NWS network are described by the NWS (1989), Linsley, Kohler, and Paulhus (Linsley, et al, 1982), Brakensiek, et al. (1979), such meteorological textbooks as Holton (2004), other NOAA and NWS documents, and similar publications.

D. Published Data—Precipitation analysis methods, data quality and quantity, data limitations, and recommended uses of data contained in technical papers are given in the papers themselves.

Understanding these methods and limitations aids in proper usage of the data and in drawing better conclusions from using the data.

(1) National Water and Climate Center

(i) NRCS's NWCC obtains, evaluates, manages, and disseminates climatic data to support agency programs and activities nationwide. The NWCC oversees the availability of agency-wide climatic data management and analysis services through the Field Office Technical Guide (FOTG) (NRCS, 2012a). Products include climate data, climate reports for soil survey regions, wetlands climate tables and documentation, delivered through the Agricultural Applied Climate Information System (AgACIS) module within FOTG. The FOTG website at http://efotg.sc.egov.usda.gov/efotg_locator.aspx (NRCS 2012a) allows the user to access data for any State and county. The NWCC also provides links to the Parameter-elevation Regressions on Independent Slopes Model (PRISM) at http://www.prism.oregonstate.edu/ (OSU 2012), which uses point measurements of precipitation, temperature, and other climate elements to produce continuous digital coverage for the United States.

(ii) The NWCC also provides climate data from their networks. The SNOw TELemetry (SNOTEL) network covers mountainous regions of the Western United States and the Soil Climate Analysis Network (SCAN) provides climate data nationally. NWCC supports hourly and 15-minute time series, along with other climatic variables offline. Make requests for these special data types to the NWCC through the appropriate State office. Equivalent data are available to the public through NOAA's NCEI.

(2) NOAA and NWS

(i) Daily amounts of rainfall measured at gages in the official networks operated by the NWS are processed and published in monthly issues of "Climatological Data" for each State by the NCEI in Asheville, NC. The NCEI website at http://www.ncei.noaa.gov/about (NCEI, 2017a) maintains station, climate, and radar data for stations throughout the continental United States, Hawaii, Guam, Puerto Rico, and the Virgin Islands. Each State has a State climatologist, who can provide information for specific storms, local data trends, and climatic data. State climatologists also coordinate observations made by weather observers throughout the States before the data are sent to the NCEI.

(ii) The times of daily measurements at stations vary as indicated in the publications. More detailed observations of storm totals and durations are available from the hourly precipitation data, also published by the NCEI for each State. Other Federal and State agencies, and universities, publish rainfall data at irregular intervals, often in a special storm reports or as research data.

(iii) Climatic data, such as precipitation, evaporation, and temperature are available for the continental United States and the Pacific and Caribbean Islands. Annual, monthly, and daily data are available in a variety of formats.

(iv) Precipitation-frequency data are available from NOAA Atlas 14 (NWS 2006a-c, 2011a-c, 2012, 2013a-b, 2015a) for both annual and partial duration series at the NWS website, http://hdsc.nws.noaa.gov/hdsc/pfds/ (NWS 2005). Annual series data are based on the analysis of precipitation data representing the maximum value occurring within a calendar year. The partial duration series data are based on analysis of the X or more largest values occurring in X years. For example, if the record length is 80 years, the highest 80 or more values are selected even though there may be two or more events in any given year and there may be years with no values selected.

(v) Standard hydrology reference books (Chow 1964, Maidment 1993) describe the difference between annual and partial duration series and how to convert from one to the other. The annual and partial duration values are significantly different for the more frequent storms, such as the 2-year and 5-year frequencies, with the partial duration value greater than the annual series value. At the 10-year and lesser frequencies, or greater return periods, differences are insignificant. The partial duration series includes the 1-year precipitation frequency whereas the annual series does not.

(vi) NRCS has historically used the partial duration series for design of engineering projects. Engineering projects are subject to all storm events and not just the largest storm of any given year. For projects where results are needed for frequent storms, the partial duration series may also be used because it includes the 1-year frequency.

(vii) The Hydrometeorological Design Studies Center (HDSC) of the NWS has a number of reports that summarize many years of weather observations over the country. The NWS uses refined statistical and error analyses to make these publications as reliable as possible. In many kinds of hydrologic work, it is unnecessary to use actual rainfall data because published analyses of data provide the required information in more usable form.

(viii) In 1975, the SCS West Technical Service Center released Technical Note Hydrology PO-6 (SCS 1975), which includes a procedure to determine the 10-day precipitation for 11 western States. The 10-day rainfall values are based on NOAA Atlas 2 (NWS 1973) data. NOAA Atlas 14 updates the data for a number of these States. However, NOAA Atlas 2 is still the most recent rainfall frequency information for Idaho, Montana, Oregon, Washington, and Wyoming. When NOAA Atlas 14 is complete for these States, procedures and information in NOAA Atlas 14 will replace PO-6.

(ix) The NOAA and NCEI collect Next Generation Weather Radar (NEXRAD) radar data and make the data and associated products available at the website www.ncdc.noaa.gov/data-access/radar-data/nexrad (NCEI 2017b). The site includes an inventory and product search link that will lead to available data, as well as a Weather and Climate Toolkit software system for download. This toolkit allows the user to import and view various radar and precipitation data. A storm event database with national publications by month and annual summary with an interactive search by date and location of a storm event database are also available.

(x) NOAA and the NWS published the following rainfall data analyses, many in cooperation with NRCS. Some of these documents may have been updated since the dates listed here. It is important that users select the most up-to-date documents for a State or area to be used for a rainfall reference unless a special study applies to that location. The list is not a complete list of precipitation frequency and PMP publications. Most of these publications are available at the NWS website http://hdsc.nws.noaa.gov/hdsc/pfds/. Other sources of published data include State and local agencies, and groups with interests in irrigation, electric supply, agricultural water use, reservoir operations, and dam safety, to name a few. The engineer should ensure that the use of alternative data is acceptable to the relevant technical and regulatory authorities. Documents covering durations from 5 minutes to 60 days and storm return periods up to 1,000 years and probable maximum precipitation (PMP):

- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 1, version 4.0: Semiarid Southwest. National Weather Service, 2006. (NWS 2006a)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 2, version 3.0: Delaware, District of Columbia, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia. National Weather Service, 2006. (NWS 2006b)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 3, version 4.0: Puerto Rico and the U.S. Virgin Islands. National Weather Service, 2006. (NWS 2006c)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 4, version 3.0: Hawaiian Islands. National Weather Service, 2011. (NWS 2011a)

- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 5, version 3.0: Selected Pacific Islands. National Weather Service, 2011. (NWS 2011b)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 6, version 2.0: California. National Weather Service, 2011. (NWS 2011c)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 7, version 1.0: Alaska. National Weather Service, 2012. (NWS 2012)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 8, version 2.0: Midwestern States. National Weather Service, 2013. (NWS 2013a)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 9, version 2.0: Southeastern States. National Weather Service, 2013. (NWS 2013b)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 10: Northeastern States (Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont). National Weather Service, 2015. (NWS 2015a)
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 11: Texas. National Weather Service, 2018. (NWS 2018)
- NOAA Atlas 2. Precipitation Atlas of the Western United States: Volume 1—Montana, Volume 2—Wyoming, Volume 5—Idaho, Volume 9— Washington, Volume 10—Oregon. National Weather Service, 1973. (NWS 1973)
- Hydrometeorological Report No. 39, Probable Maximum Precipitation in the Hawaiian Islands. U.S. Weather Bureau, 1963. (Weather Bureau 1963a)
- Hydrometeorological Report No. 41, Probable Maximum and TVA Precipitation over the Tennessee River Basin above Chattanooga. U.S. Weather Bureau, 1965. (Weather Bureau 1965)
- Hydrometeorological Report No. 42, Meteorological Conditions for the Probable Maximum Flood on the Yukon River above Rampart, Alaska. U.S. Weather Bureau, 1966. (Weather Bureau 1966)
- Hydrometeorological Report No. 47, Meteorological Criteria for Extreme Floods for Four Basins in the Tennessee and Cumberland River Watersheds. National Oceanic and Atmospheric Administration and Tennessee Valley Authority, 1973. (NOAA and TVA 1973)
- Hydrometeorological Report No. 48, Probable Maximum Precipitation and Snowmelt Criteria for Red River of the North above Pembina, and Souris River above Minot, North Dakota. National Oceanic and Atmospheric Administration and U.S Army Corps of Engineers, 1973. (NOAA and USACE 1973)
- Hydrometeorological Report No. 49, Probable Maximum Precipitation Estimates, Colorado River and Great Basin drainages, National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers, 1977, reprint 1984. (NOAA and USACE 1984)
- Hydrometeorological Report No. 50, Meteorology of Important Rainstorms in the Colorado River and Great Basin Drainages. National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers, 1981. (NOAA and USACE 1981)
- Hydrometeorological Report No. 51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers, 1978. (NOAA and USACE 1978)
- Hydrometeorological Report No. 52, Application of Probable Maximum Precipitation Estimates—United States East of the 105th Meridian. National Oceanic

and Atmospheric Administration and U.S. Army Corps of Engineers, 1982. (NOAA and USACE 1982)

- Hydrometeorological Report No. 53, Seasonal Variation of 10-square-mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. National Oceanic and Atmospheric Administration and U.S. Nuclear Regulatory Commission, 1980. (NOAA and NRC 1980)
- Hydrometeorological Report No. 54, Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska., National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers, 1983. (NOAA and USACE 1983)
- Hydrometeorological Report No. 55A, Probable Maximum Precipitation Estimates United States Between the Continental Divide and the 103rd Meridian, Report and Plates I-VI. National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineer, and Bureau of Reclamation, 1988. (NOAA, USACE, and BOI 1988)
- Hydrometeorological Report No. 56, Probable Maximum and TVA Precipitation Estimates with Areal Distribution for Tennessee River Drainages Less Than 3,000 mi2 in Area. National Oceanic and Atmospheric Administration and Tennessee Valley Authority, 1986. (NOAA and TVA 1986)
- Hydrometeorological Report No. 57, Probable Maximum Precipitation – Pacific Northwest States: Columbia River (including portions of Canada), Snake River and Pacific Coastal Drainages. National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, and Bureau of Reclamation, 1994. (NOAA, USACE, and BOI 1994)
- Hydrometeorological Report No. 58, Probable Maximum Precipitation in California - Calculation Procedure. National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers, 1998. (NOAA and USACE 1998)
- Hydrometeorological Report No. 59, Probable Maximum Precipitation in California - Shapefiles. National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers, 1999. (NOAA and USACE 1999)
- Technical Paper No. 40, Rainfall Frequency Atlas of the United States, U.S. Weather Bureau, 1961. (Weather Bureau 1961a)
- Technical Paper No. 42, Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands, U.S. Weather Bureau, 1961. (Weather Bureau 1961b)
- Technical Paper No. 47, Probable Maximum Precipitation and Rainfall- Frequency Data for Alaska. U.S. Weather Bureau, 1963. (Weather Bureau 1963b)
- Technical Paper No. 49, Two- to Ten-Day Precipitation for Return Periods of 2 to 100 years in the Contiguous United States, U.S. Weather Bureau, 1964. (Weather Bureau 1964)
- NOAA Technical Memorandum NWS HYDRO-35, Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States, National Weather Service, 1977. (NWS 1977)
- NOAA Technical Memorandum NWS HYDRO-39, Probable Maximum Precipitation Maximum Precipitation for the Upper Deerfield Drainage Massachusetts/Vermont. National Weather Service, 1984. (NWS 1984)
- NOAA Technical Memorandum NWS HYDRO-41, Probable Maximum Precipitation Estimates for the Drainage above Dewey Dam, Johns Creek, Kentucky. National Weather Service, 1985. (NWS 1985)
- NOAA Technical Memorandum NWS HYDRO-45, Relationship between Storm and Antecedent Precipitation over Kansas, Oklahoma, and Eastern Colorado. National Weather Service, 1995. (NWS 1995a)

- NOAA Technical Memorandum NWS HYDRO-46, A Climatic Analysis of Orographic Precipitation over the Big Horn Mountains. National Weather Service, 1995. (NWS 1995b)
- NOAA Technical Report NWS 21, Interduration Precipitation Relations for Storms – Southeast States. National Weather Service, 1979. (NWS 1979)
- NOAA Technical Report NWS 25, Comparison of Generalized estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls. National Weather Service, 1980. (NWS 1980)
- NOAA Technical Report NWS 27, Interduration Precipitation Relations for Storms – Western United States. National Weather Service, 1981. (NWS 1981)
- Short duration rainfall relations for the western United States, 1986. Arkell, R.E. and F. Richards. Preprint volume of the Conference on Climate and Water Management, American Meteorological Society, pp 136-141. (Arkell and Richards 1986)

(xi) The NOAA and NWS publications are available from the HDSC websites http://www.nws.noaa.gov/oh/hdsc/relevant_publications.html and http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html. Engineers should visit these websites to download reports and data as well as look for periodic updates of reports.

(3) Northeast Regional Climate Center (NRCC)—The NRCC completed a precipitation-frequency analysis for New York and New England States of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island in 2012. Rainfall data for New York and the New England States are found at the NRCC website http://precip.eas.cornell.edu/ (NRCC 2012). The NWS published the updated NOAA Atlas 14 volume 10 for New York and the New England States in 2015. The updated NOAA Atlas 14 should be used for NRCS projects in these States.

E. Unpublished Data

(1) Various Federal and State agencies sometimes make field surveys after an unusually large storm to collect bucket survey data. Bucket surveys are measurements of rainfall caught in narrow-bore tubes, such as those available in hardware or agricultural supply stores, buckets, watering troughs, bottles, and similar containers. Ordinarily, these data are used to give more detail to rainfall maps based on standard gage data. The bucket gage data should be carefully evaluated. Data from bucket surveys are generally not published but are available in the offices of the gathering agency.

(2) Narrow-bore tubes used by many farmers and ranchers have given results almost equal to those from standard gages. These tube gages must be properly exposed and serviced to obtain such results. Many farmers, ranchers, and individuals keep a daily or storm record of measured rainfall amounts. Newspaper offices, banks, water-treatment plants and municipal offices often collect measurements at their own gages and keep daily records. These data are recommended for use with hydrologic model calibration for a historical storm or as a reference to historical storms. Use of unpublished data for design purposes is not recommended.

630.0402 Rainfall Over a Watershed

A. In watershed studies, it is often necessary to know the average depth of rainfall over an area. The methods described apply to both the estimation of average storm event rainfall and average rainfall or precipitation for a certain time period, such as annual or monthly.

B. The average depth can be determined in various ways, depending on the kind of data used. If the rainfall amount is taken from one of the NWS documents, it is for a specific point and the point-area relationship given in the paper is used to estimate the average depth over the area. It is difficult to obtain an average depth from data of several rain gages because the number and locations of gages and storm variability influence the results. Manual and geospatial methods of using such data are given in this section. The choice of methods depends to some extent on what data are available and where data are available and to some extent on the background and preference of the user.

C. Methods of Estimating Average Depths

(1) Use of One Gage

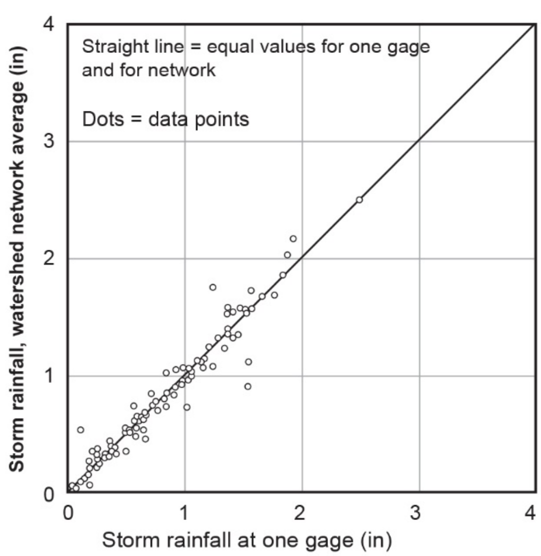
(i) How well the rainfall measured at a single gage represents the average depth over an area depends on—

- Distance from the gage to the center of the area.
- Size of the area.
- Relative areal extent of significant storm rainfall with respect to the watershed area.
- Duration and frequency of rainfall amounts being analyzed.
- Orographic and other effects of the topography of the locality.

(ii) Figures 4-1 through 4-4 illustrate the effects of the first two influences. Since areal extent, duration, and frequency of rainfall amounts are not directly apparent in figures 4-1 through 4-4, they are two of the reasons why there may be significant scatter in the plotted points.

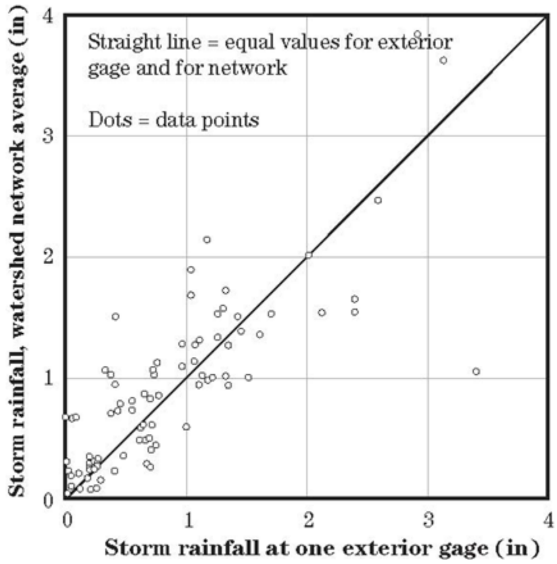
(iii) The effect of distance from the center of the watershed to the gage is shown in figures 4-1 and 4-2. A single gage is located near the center of a 0.75-square-mile watershed (fig. 4-1). Measured storm rainfalls at the gage are seen to be quite close to the watershed averages, which were determined using a dense network of gages.

Figure 4-1: Measured Storm Rainfall at One Interior Watershed Gage Compared to an Interior Network



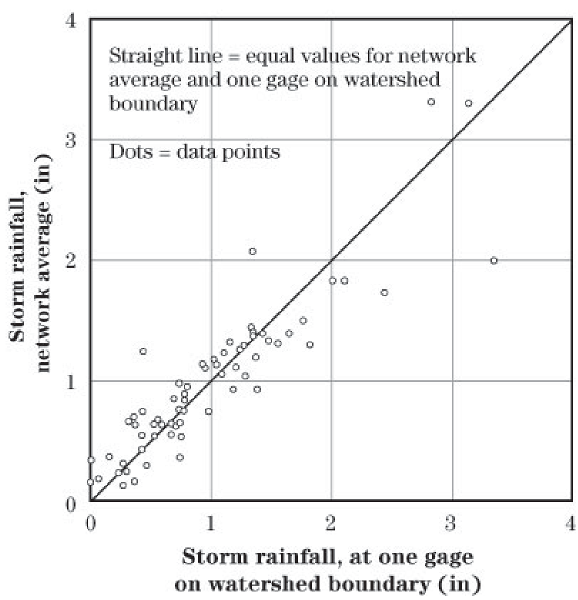
(iv) However, in figure 4-2, where the gage is located 4 miles outside the watershed boundary, the measured storm rainfalls at the gage often differ significantly in the statistical sense from the watershed averages.

Figure 4-2: Measured Storm Rainfall at One Interior Watershed Gage Compared to an Outside Gage



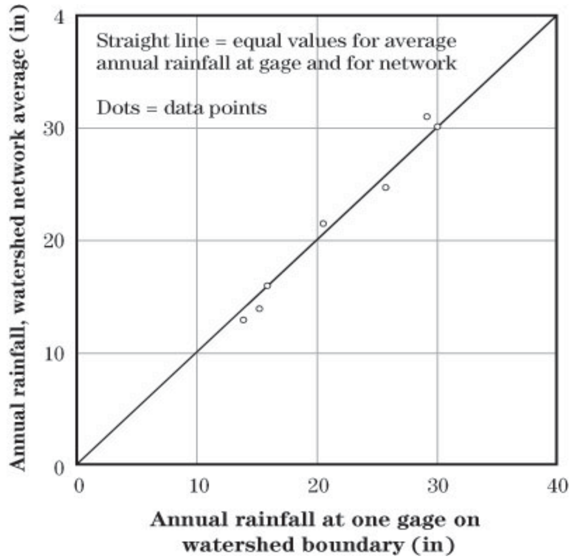
(v) A similar effect occurs when the area of application is increased, as shown in figure 4-3, where the storm rainfall measured at a gage on the boundary of a 5.45 square mile watershed is compared to the results from a denser net of gages.

Figure 4-3: Measured Storm Rainfall at One Gage on the Watershed Boundary Compared to Average Storm Rainfall



(vi) In figure 4-4, the watershed average annual rainfall measured at the single gage on the watershed boundary is compared to the watershed average annual rainfall measured by the denser network of gages. Figures 4-1 through 4-4 are all from data from ARS Experimental Agricultural Watersheds in Hastings, NE.

Figure 4-4: Measured Annual Rainfall at One Gage on the Watershed Boundary Compared to Average Annual Rainfall



(vii) The correspondence between measured storm rainfall and area averages is close where the rainfall amounts being used are sums, such as monthly or annual rainfalls, because the variations for single storms tend to offset each other. The gage and watershed used for figure 4-3 are also used in figure 4-4 where annual rainfalls are plotted. The differences between gage and watershed amounts in figure 4-4 are considerably smaller than those for the individual storm comparisons of figure 4-3.

(viii) The correspondence between gage and area amounts is also close if the storm rainfalls are used with the methods shown in 210-NEH-630-18 (NRCS 2012b) to construct frequency lines for gage and area amounts. The correspondence occurring then is for amounts having the same frequency.

(ix) The examples use data taken from a non-mountainous region where orographic influences are not significant; otherwise, the results might be very different. The examples show that the use of a single gage may lead to errors in areal estimates and raises the question of how much error is permissible. Accuracy of rainfall estimates is described in section 630.0402D of this chapter.

(2) Isohyetal Method

(i) The spacing of gages in an areal network is seldom sufficiently uniform to permit use of the numerical average of the gage measured storm rainfall as the area average. An isohyet is a line connecting points of equal rainfall depth. Isohyetal maps are often used, with networks of any configuration, to get area averages or for studies of rainfall distributions. The map is made by drawing the lines in the same manner that contour lines are drawn on topographic maps, using the gage locations as data points.

(ii) Example 4-1.—Figures 4-5 through 4-8 illustrate the construction and application of the isohyetal method to a research watershed in Nebraska. Four rain gages are associated with the watershed; two are within the watershed boundaries, one is on the boundary, and a fourth is just outside the watershed, as in figure 4-5. The open circles are centered on the gage locations. The rainfall amounts are 1.40, 1.54, 1.94, and 1.55, going clockwise from the upper left.

- Step 1.—Locate the rain gages on the watershed map and plot the rainfall amounts as shown on figure 4-5.

- Step 2.—Interpolate the amounts falling between the rain gages. Figure 4-6 shows one such line.
- Step 3.— Using the estimated rainfalls of step 2, develop isohyets to cover the whole watershed as illustrated on figure 4-7. Determination of the orientation of the lines is subjective with the limited data shown in figure 4-6. Data from local bucket surveys may contribute significantly to locating the lines, if the bucket survey data are carefully evaluated. For the good quality bucket survey data collected, plot the location on the map and record the rainfall volume. Use these values as additional rain gage locations and measurements in the method selected to determine the average watershed rainfall.

Figure 4-5: Rain Gage Locations and Amounts in a Small Nebraska Watershed

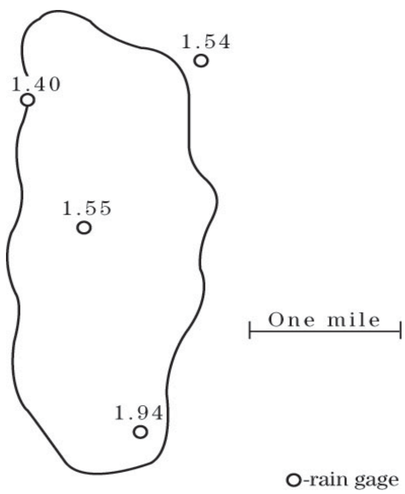


Figure 4-6: Estimate the Rainfall Amounts Falling Between the Gage Locations

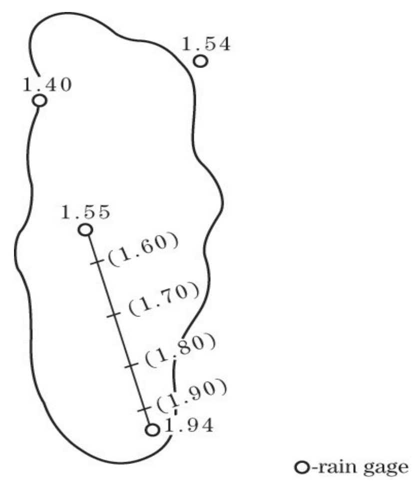
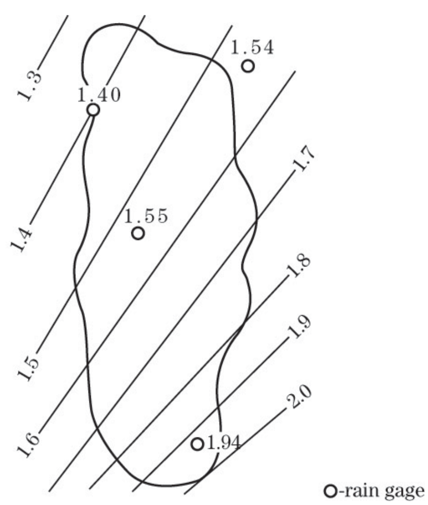


Figure 4-7: Isohyetal Map Developed from Figure 4-5 and Figure 4-6



- Step 4.— Determine the land area between each adjacent isohyet and get the watershed average by weighting the rainfall depths for the parts as in figure 4-8. For this example, the area covered by each isohyet was measured using a dot counter. A dot counter is a transparent sheet with dots placed in a grid format of equal horizontal and vertical spacing. Prior to general use of GIS, it was a good quick method to estimate areas of land delineated on maps. For this example, the total area is the sum of all the individual parts, or 174 dots. The percentage of the total area in each isohyet is the number of points in column 3 divided by 174 and is listed in column 4. The weighted amount of rainfall in each isohyetal area is calculated as column 2 times column 4 and is listed in column 5. The sum of the weighted amounts gives the average watershed rainfall, 1.61 inches.

Figure 4-8: Tabulation of Isohyetal Weights from Figure 4-7.

Rainfall limits (in)	**Rainfall (in)**	**Number of points***	**Fraction of area**	**Rainfall weighted by area**
(1)	(2)	(3)	(4)	(5)
<1.4	1.4	5	0.03	0.042
1.4–1.5	1.45	38	0.22	0.319
1.5–1.6	1.55	47	0.27	0.418
1.6–1.7	1.65	37	0.21	0.346
1.7–1.8	1.75	28	0.16	0.28
1.8–1.9	1.85	11	0.06	0.111
>1.9	1.9	8	0.05	0.095
Totals		174	1.00	1.611
	Average rainfall			1.61 in

*The number of points was determined using a dot counter, a method of estimating area.

(iii) A denser network may give a more complicated isohyetal map as in figure 4-9, where the total rain gage network on this research watershed is used to depict the storm.

(iv) Figure 4-10 tabulates the data for figure 4-9. There are changes in depth on parts of the watershed, but the watershed average of 1.63 inches is not significantly different from the estimate derived from figure 4-7 and computed in figure 4-8. Generally, the more gages or rainfall depth measurements there are, the more accurate the estimate of mean precipitation over an area. A particular network may be excessively close for one kind of estimate at the same time that it is too open for another kind. The relative error of an area average obtained through use of a network can be estimated as shown in Section 630.0402D, "Accuracy."

Figure 4-9: A Denser Rain Gage Network Providing a More Detailed Isohyetal Map

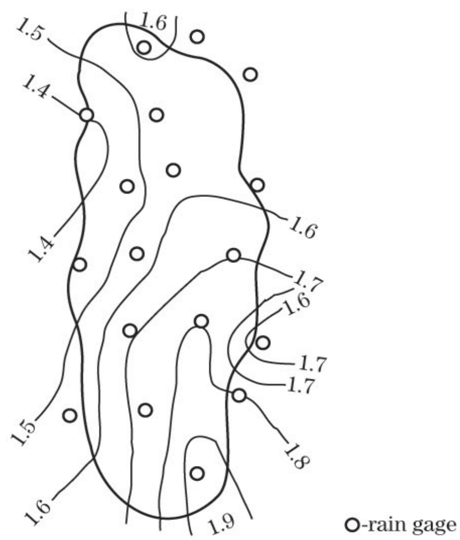


Figure 4-10: Tabulation of Watershed Rainfall from Isohyetal Map (fig. 4-9).

Rainfall limits (in)	Rainfall (in)	Number of points*	Fraction of area	Rainfall weighted by area
(1)	(2)	(3)	(4)	(5)
<1.4	1.4	3	0.02	0.028
1.4–1.5	1.45	25	0.14	0.203
1.5–1.6	1.55	58	0.33	0.511
1.6–1.7	1.65	31	0.18	0.297
1.7–1.8	1.75	34	0.20	0.35
1.8–1.9	1.85	17	0.10	0.185
>1.9	1.9	6	0.03	0.057
Totals		174	1.00	1.631
Average rainfall				**1.63 in**

*The number of points was determined using a dot counter, a method of estimating area.

(3) Thiessen Method

(i) Another method of using a rain gage network for estimating watershed average depths especially suitable for electronic computation is the Thiessen method, shown in figures 4-11 through 4-13. In this method, the watershed area is divided into subareas using rain gages as hubs of polygons. The subareas are used to determine ratios that are multiplied by the subarea rainfall and summed to get the watershed average depth. The ratios are the percentages of area in the basin represented by each rain gage. Construction of the polygon diagram is illustrated in figures 4-11 and 4-12.

Figure 4-11: Watershed with Three Rain Gages Analyzed by the Thiessen Method

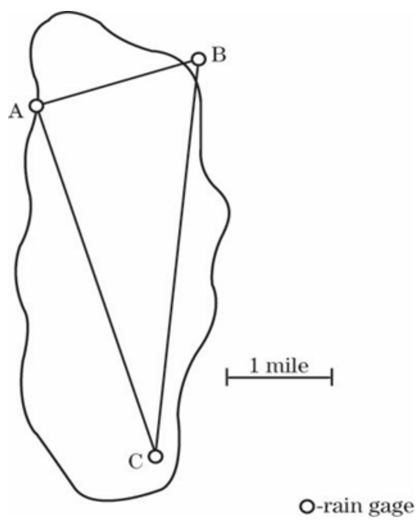
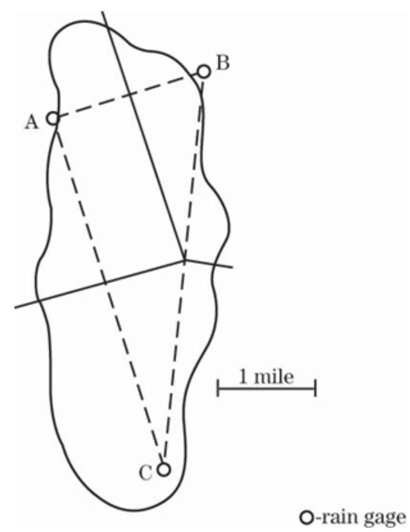


Figure 4-12: Thiessen Weights Method – Step 2.



(ii) The Thiessen weights are the ratio of the gage's polygon area divided by the area of the entire watershed, as indicated in figure 4-13. Watershed average depths are computed as shown in figure 4-14. If a gage is added or removed from the network, a new diagram must be drawn and new weights computed. Figure 4-15 shows the Thiessen method for a denser rain gage network.

Figure 4-13: Determination of Thiessen Weights – Step 3.

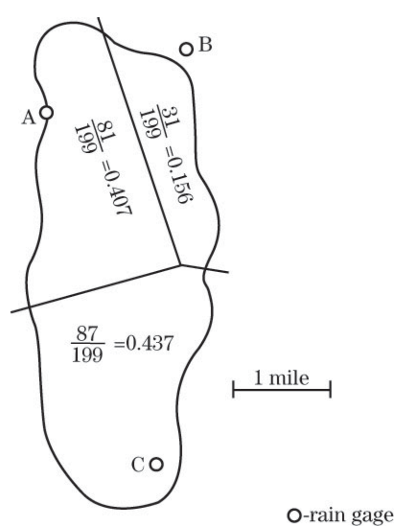
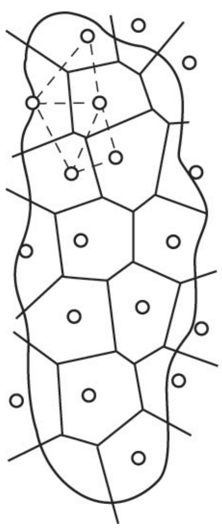


Figure 4-14: Watershed Rainfall Depth by the Thiessen Method Applied to figure 4-13.

Rain gage ID	Measured rainfall (in)	Thiessen weight	Weighted rainfall (in)
A	1.40	0.407	0.570
B	1.54	0.156	0.240
C	1.94	0.437	0.848
	Sum	1.000	1.658

The watershed weighted rainfall depth is 1.658 inches, which is rounded to 1.66 inches.

Figure 4-15: A Denser Thiessen Network



(iii) Example 4-2.—This example demonstrates the Thiessen method using three rain gages.

- Step 1.—Draw lines connecting the rain gages, as in figure 4-11.
- Step 2.—Draw lines bisecting the lines connecting the gages, as in figure 4-12.
- Step 3.—Compute the weight of each polygonal section within the polygon as shown in figures 4-13 and 4-14. The total area of the watershed was computed to be 199 acres. The rainfall at gage A is 1.40 inches, that at gage B is 1.54 inches, and that at gage C is 1.94 inches. The areas of each individual polygon were computed to be 81, 31, and 87 acres, with Thiessen weights of 0.407, 0.156, and 0.437 respectively. Each area weight multiplied by the gage rainfall yields the weighted rainfall for that gage, as shown in figure 4-14.

(iv) The denser Thiessen network will generally yield a slightly different answer. The Thiessen method is not used to estimate rainfall depths of mountainous watersheds since elevation is a strong factor influencing the areal rainfall distribution (see Section 630.0402E, "Orographic influences").

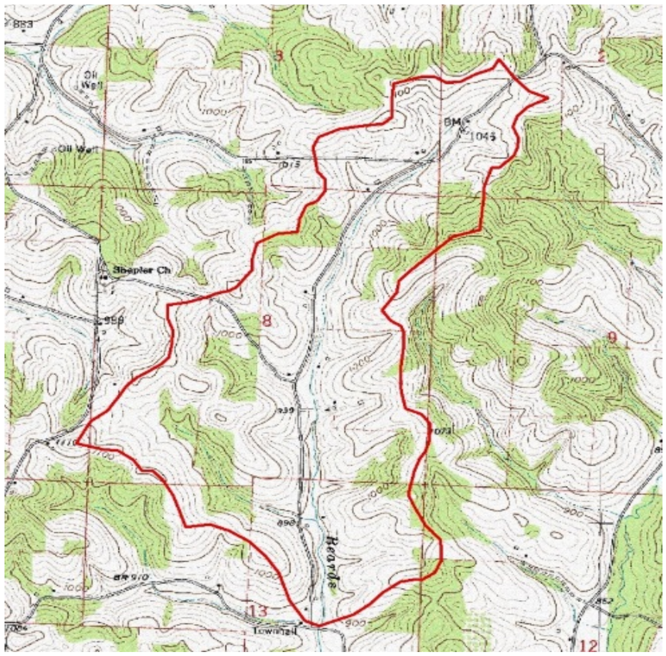
(4) Use of GIS to Create an Isohyetal Map and Compute Mean Precipitation

(i) An isohyetal map may be created for a layer of points each with a rainfall amount using GIS. There are various options using GIS software to develop a surface based on the rainfall points. The surface, a product of this technology, is a grid layer with a rainfall value for each cell. A specific cell size, such as 10 meters or 30 meters or larger, must be selected. From this grid layer of rainfall and a GIS layer of the watershed boundary, statistics including the maximum, minimum, and mean rainfall for the watershed may be computed.

(ii) Figure 4-16 was developed for a small watershed in Coshocton County, OH, using GIS methods.

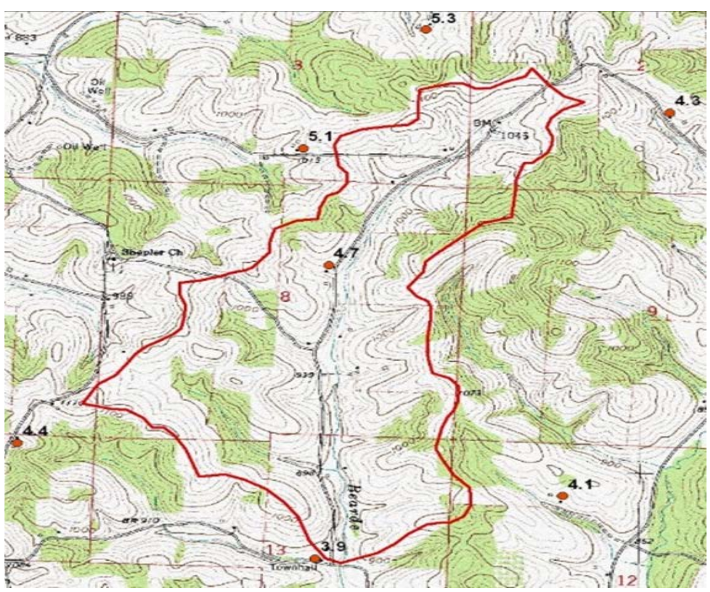
- **Step 1.**—Digitize the watershed boundary (fig. 4-16).

Figure 4-16: Digitized Watershed Boundary for a Watershed in Coshocton County, OH.



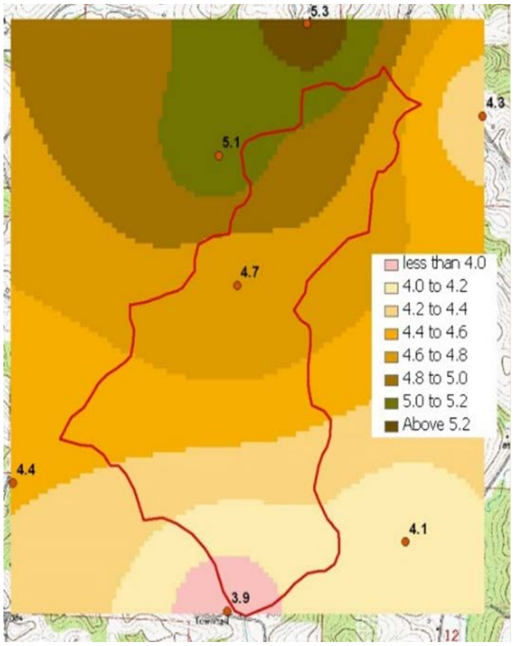
- **Step 2**.—Develop a point layer with the rainfall point measurements in inches (fig. 4-17).

Figure 4-17: Point Rainfall Measurements for a Watershed in Coshocton County, OH.



- **Step 3**.—Many NRCS offices use Environmental Sciences Research Institute (ESRI) GIS software (ESRI 2012). Therefore, the example refers to commands in the ESRI GIS software. The "Spatial Analyst Interpolation" command in ArcGIS is used to generate the isohyetal map in figure 4-18. Other GIS software should have similar capabilities.

Figure 4-18: Isohyetal Map based on the Point Rainfall Measurements in figure 4-17.



- **Step 4**.—The "Spatial Analyst Zonal Statistics as Table" command executed in ArcGIS produces figure 4-19 where the minimum, maximum, range, and mean rainfall for the watershed are computed in the last four columns. The mean rainfall is 4.54 inches. The first two columns contain GIS identifiers. The next two columns are the number of rasters inside the watershed and the area of the watershed in square meters. The last four columns give the minimum, the maximum, the range, and the mean of the rainfall values.

Figure 4-19: Table of Zonal Statistics Generated by Spatial Analyst Zonal Statistics in GIS Program

Table

zone_rainfall

Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN
1	0	3423	3080700	3.902358	5.116686	1.214328	4.54379

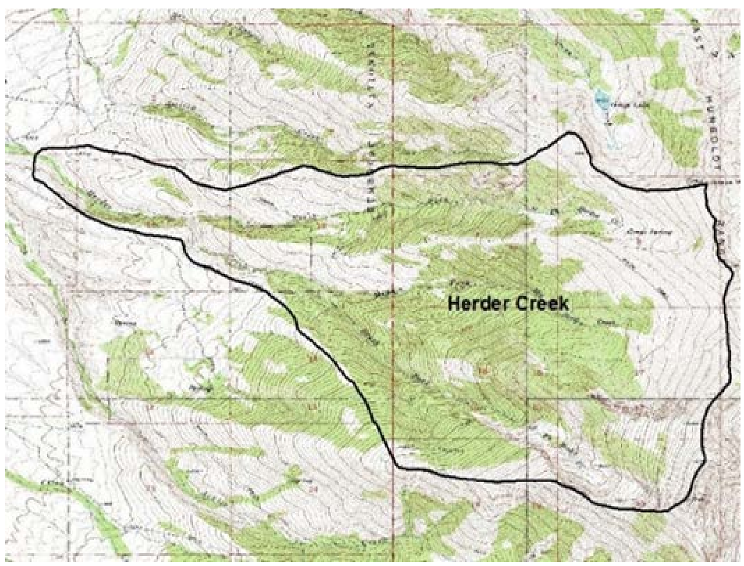
(5) Use of NOAA Atlas 14 GIS Data to Derive Mean Watershed Precipitation

(i) If the watershed is of significant size (more than about 1 square mile), a point value of rainfall may not be accurate. Instead, a mean rainfall for the watershed may be more representative. If the storm event rainfall varies within the watershed, an areal mean may be calculated using GIS.

(ii) This example illustrates how to calculate an areal mean 25-year, 24-hour rainfall for a watershed using NOAA Atlas 14 GIS data and data from Herder Creek in Elko County, NV.

- Step 1.—Download and prepare the GIS rainfall grid for desired durations and return periods. For this example, download the 25-year 24-hour GIS grid for the western State region (which includes Nevada) from the NOAA Atlas 14 website. Prepare the grid according to instructions available from the National Water Quality and Quantity Team West National Technology Support Center (WNTSC) website http://go.usa.gov/rXYw under "Technical Information."
- Step 2.—Digitize the watershed boundary on a base map such as a digital raster graphic map (DRG), and develop the drainage area from GIS commands, such as ESRI ArcHydro Tools or Spatial Analyst, or from the Watershed Boundary Dataset (WBD), GIS maps available for watersheds with defined hydrologic unit codes (https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/water/watersheds/dataset/, USGS, 2013). For the Herder Creek, NV, watershed, digitize the boundary directly from a DRG (fig. 4-20).

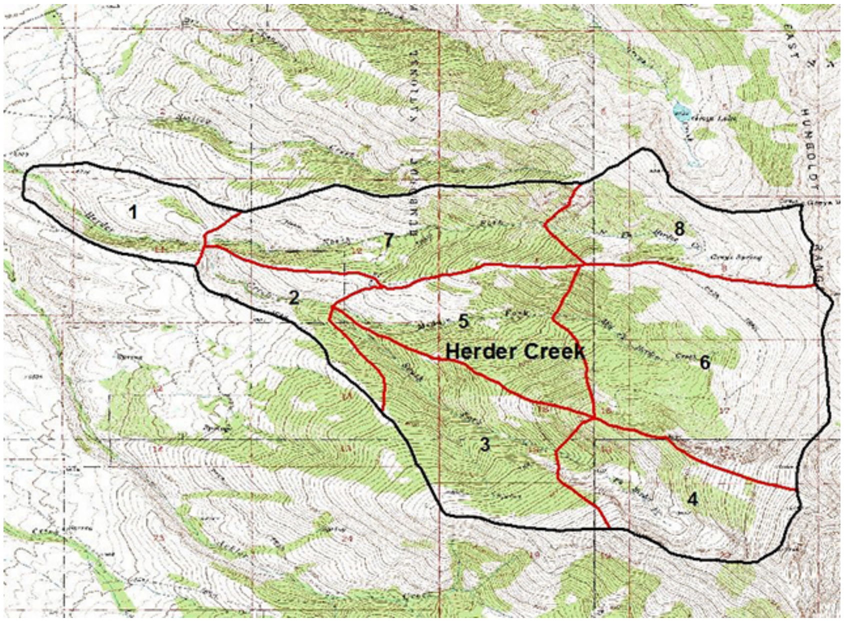
Figure 4-20: Watershed Boundary for Herder Creek, NV



(iii) Use the ESRI Identify icon to determine that the 25-year 24-hour rainfall at the far western edge of the watershed is 2.78 inches and at the far southeastern edge of the watershed is 4.07 inches. This is a significantly large range of rainfall. Treating this watershed as a homogeneous unit assumes a single runoff curve number, time of concentration, and uniform rainfall.

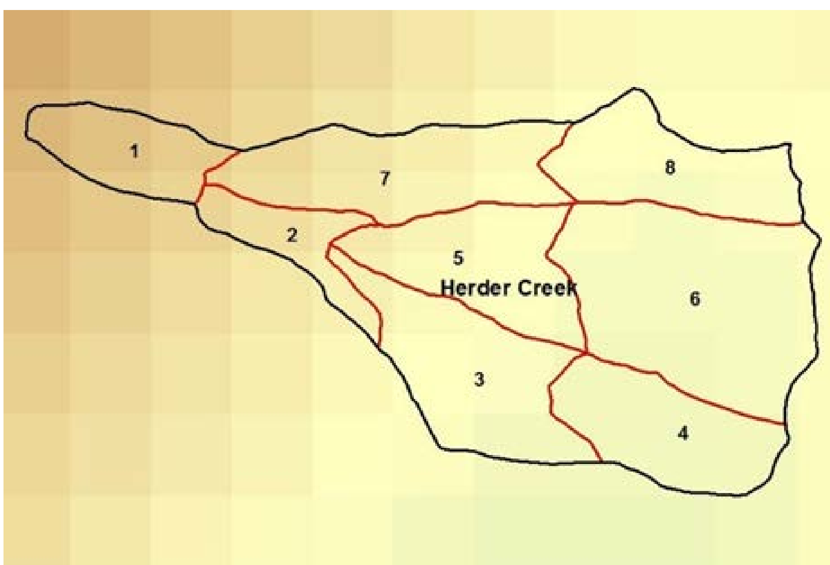
(iv) An alternative is to divide the watershed into subareas and determine the mean rainfall for each subarea. This allows for each subarea to have its own individual runoff curve number and time of concentration and rainfall value. Figure 4-21 shows the watershed divided into eight subareas.

Figure 4-21: Herder Creek, NV, Watershed Divided into 8 Subareas



(v) Figure 4-22 shows the watershed boundary divided into subareas overlaid on the GIS rainfall grid. The rainfall grid has about a half-mile or about 800-meter resolution.

Figure 4-22: Herder Creek, NV, Watershed Boundary Overlaid on the Rainfall Grid



(vi) Each raster has a rainfall value assigned. The beige colors on the western edge represent the lowest rainfall values and the yellow-green rasters on the southeastern edge of the watershed represent larger values. Execute the ESRI GIS command “Spatial Analyst Zonal Statistics” to derive the statistics for each of the eight subareas. These statistics include area, maximum, minimum, range, mean, and standard deviation. In figure 4-23, only the area and mean rainfall are shown.

Figure 4-23: GIS Areal and Rainfall Statistics for Herder Creek, NV

Area number	Area (mi^2)	Mean 25-yr, 24-hr rainfall
1	0.49	2.86
2	0.36	3.32
3	0.96	3.89
4	0.76	4.05
5	0.79	3.82
6	1.63	4.00
7	1.00	3.66
8	0.75	3.94

The total watershed area is 6.74 square miles. The mean rainfall calculated for the total watershed is 3.79 inches.

(6) Other Methods - Other methods for estimating areal average rainfall from a system of point rain gage measurements include the Reciprocal-Distance-Squared method (Wei and McGuiness 1978; Singh and Chowdhury 1986) and use of geostatistics (kriging) (McCuen and Snyder 1986, Bras and Rodriguez-Iturbe 1985).

D. Accuracy

(1) Accuracy of any rainfall estimate depends mainly on the distance between a gage and the point of application of the estimate, regardless of the method used. In mountainous areas, the vertical distance may be more important than the horizontal, but for flat or rolling terrain, only the horizontal distance typically matters. Exceptions occur where rain shadows and lake effect precipitation may vary greatly across a large watershed that does not have large relief variability. For a network, both distance and arrangement of gages affect the accuracy. Unless special studies at a gage site have been made, the possible differences between gage and average watershed rainfalls are generally ignored.

(2) Figure 4-24 can be used to estimate the range of possible differences likely to occur 7 times out of 10 if the measured storm rainfall at a single gage is used as a depth for a location some distance away. It was developed from information given by Huff and Neill (1957) for small areas in Illinois. The watersheds studied ranged from 19 acres to 400 square miles. Even though this report includes watersheds located in Illinois, the procedures may be applicable in neighboring States.

(3) Figure 4-24 has limits on storm rainfall of 10 inches and horizontal distance of 10 miles. Equation 6 on page 31 of the Huff and Neill reference represents one standard deviation and is included in this chapter. One standard deviation is added and subtracted from the storm rainfall to represent the 70 percent probability. Horizontal distance is used, so figure 4-24 does not apply in mountainous areas or high desert country (see Section 630.0402E, "Orographic Influences"). These examples show how the diagram can be used.

(4) The equation used to develop figure 4-24 is—

$$RI = 10^{(0.31\log D + 0.51P^{(0.5)} - 0.961)} \qquad \text{(equation 4-1)}$$

Where—

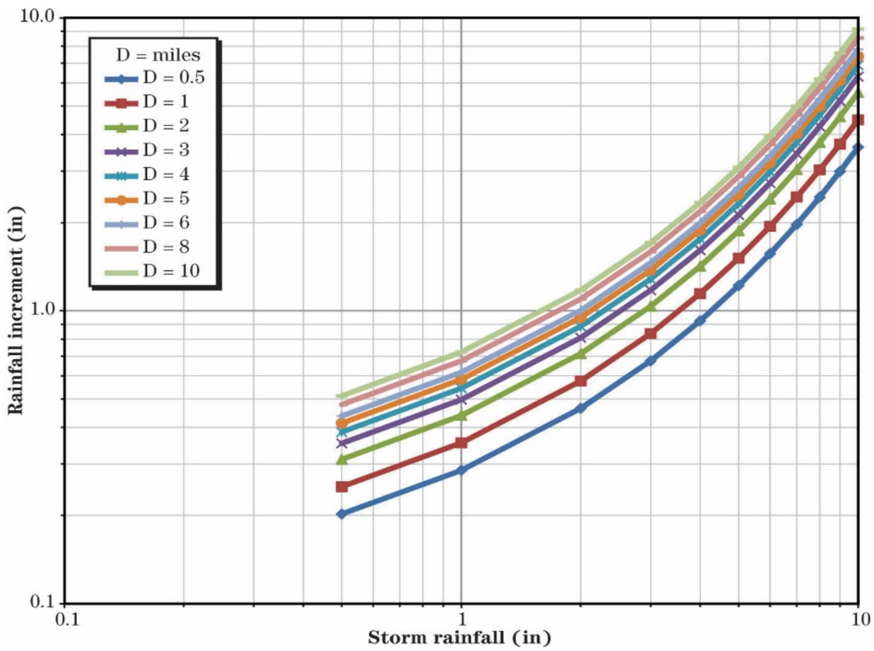
RI = rainfall increment.

D = distance from gage, miles.

P = storm rainfall, inches.

Log = base 10 logarithm.

Figure 4-24: Estimating the Possible Difference in Transposed Rainfall Amounts (Modified from Huff and Neill, 1957).



(5) **Example 4-3**—The storm rainfall depth at a gage is 3.5 inches. What rainfall depth is likely to have occurred, with a probability of 0.7 (7 chances out of 10), at a point 5 miles away from the gage?

(i) Step 1.—Using figure 4-24 with the storm rainfall of 3.5 inches, and at the intersection of the 5-mile line, read a rainfall increment of 1.62 inches.

(ii) Step 2.—Compute the range of rainfall likely to have occurred seven chances out of ten. The limits are 3.5 + 1.62 = 5.12 inches, and 3.5 - 1.62 = 1.88 inches. Therefore, where the gage has a measured storm rainfall of 3.5 inches, there is a probability of 0.7 (7 chances out of 10) that the rainfall depth at a point 5 miles away from the gage is between 1.88 and 5.12 inches.

(6) **Example 4-4**

(i) In example 4-4, figure 4-25 shows the variations to be expected when data from two gages are used to estimate the rainfall depth, and also when the gages are nearer or farther apart.

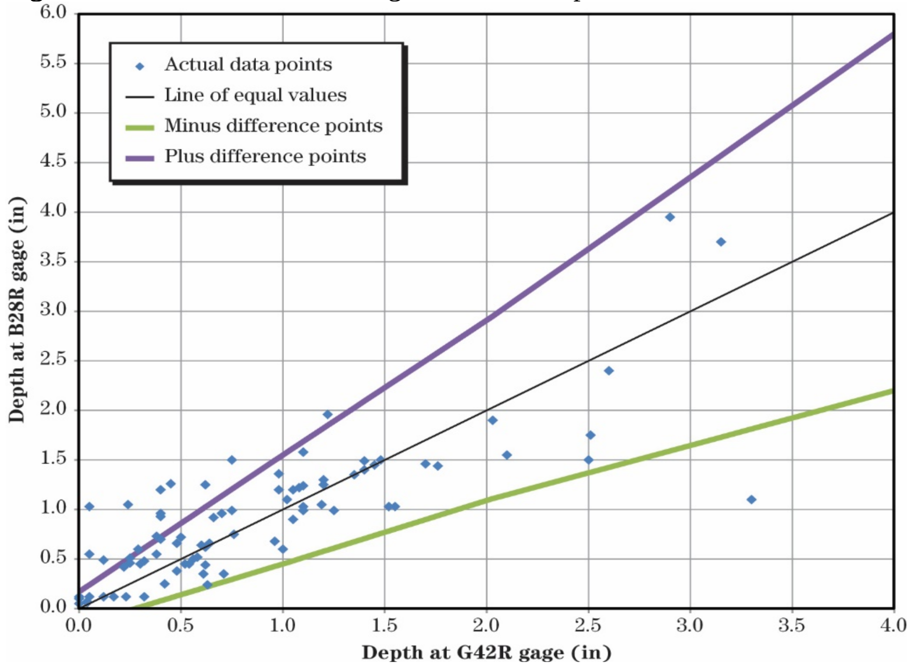
(ii) Rain gages B28R and G42R, on the Agricultural Research Service watershed in Webster County, NE, are 4.3 miles apart. Given any storm rainfall of 0 to 4 inches depth at G42R, compute the range of difference to be expected if the rainfall at B28R is to be estimated from that at G42R using figure 4-20. After plotting, the difference lines on figure 4-24, compare the computed range with the plotting of actual data points for the two gages.

- Step 1.—Plot a line of equal values.
- Step 2.—Select four values on the G42R depth scale. These values will be used with figure 4-24 or equation 4-1. For this example, the selected values are 0, 1, 2, and 4 inches.
- Step 3.—Using figure 4-24 or equation 4-1 with the distance of 4.3 miles and at the intersections of the 1-, 2-, and 4-inch rainfall lines read plus and minus differences of

0.55, 0.90, and 1.80 inches, respectively. Use equation 4-1 to calculate a value for zero inches of 0.17.

- Step 4.—At 1 inch of rainfall depth at gage G42R plot points at rainfall depths of 0.45 inches and 1.55 inches (1 in plus and minus 0.55 in). At 2 inches of rainfall depth at gage G42R plot points at rainfall depth of 1.10 inches and 2.90 inches. At 4 inches of rainfall depth at gage G42R plot points at rainfall depth of 2.20 inches and 5.80 inches. At zero inches of depth at gate G42R plot the points plus and minus 0.17 inches of depth for gage B28R.
- Step 5.—Connect the four plus difference points and four minus difference points by lines as shown on figure 4-25. The plot of the lower limit line is not shown below zero inches of rainfall. The plotted points in the figure are for actual measurements at the gages. One point is less than the lower difference line and 13 points are above the upper difference line. Since there are 82 points, 17 percent of the points fall outside the 70 percent confidence interval. This could be expected because there is generally more variation of storm rainfall when considering a limited number of events at two gages than when considering many events at many rain gages.

Figure 4-25: Storm Rainfall Gages 4.3 Miles Apart



(iii) One advantage in using figure 4-24 is that where a rainfall estimate is to be made for some distant point, the difference lines can be drawn in advance to give an idea of the value of the estimate.

E. Orographic Influences

(1) In hilly or mountainous terrain, the relief may be enough to affect the amount and distribution of precipitation so that measured storm rainfalls are influenced by physiographic variables, both local and distant. Some of these are—

(i) Elevation or altitude.
(ii) Local slope.
(iii) Orientation or aspect of the slope.
(iv) Distance from the moisture source.

(v) Topographic barriers to incoming moisture.

(vi) Degree of exposure, which is defined as the sum of those sectors of a circle of 20-mile radius centered at the station, containing no barrier 1,000 feet or more above station elevation, expressed in degrees of arc of circle (azimuth) (Hiatt 1953).

(2) In a typical watershed study, it is seldom possible to determine the influences of all these variables. Orographic effects can be simulated in a hydrologic model by dividing the watershed into subareas related to elevation. A different rainfall may be used for each subarea.

(3) Figures 4-26 and 4-27 show an example of the influences of altitude and topographic barriers on rainfall in a local example. The rainfall amounts indicated by the points in figure 4-26 were recorded during the storm of February 27 to March 4, 1938, in southern California, in the vicinity of the Santa Ana, San Bernardino, and San Gabriel mountains, which lie roughly parallel to the California coast. The series of moisture-laden air masses associated with the storms swept in from the Pacific Ocean to encounter the mountain ranges at almost right angles to their path. The mountains acted as obstructions, thrusting the warm, moist air upward into colder air, and the resultant rapid condensation produced excessively heavy rainfall, particularly on the coastal side of the ranges. The desert side of the ranges (figure 4-27) had significantly less rainfall. Much of the moisture had already been pulled out of the air mass by the time it reached the desert side of the ranges. As the air mass warmed moving down the desert side of the mountain slopes, it no longer had a ready moisture source and thus became drier.

Figure 4-26: Orographic Influences on Rainfall (Source: USGS 1942)

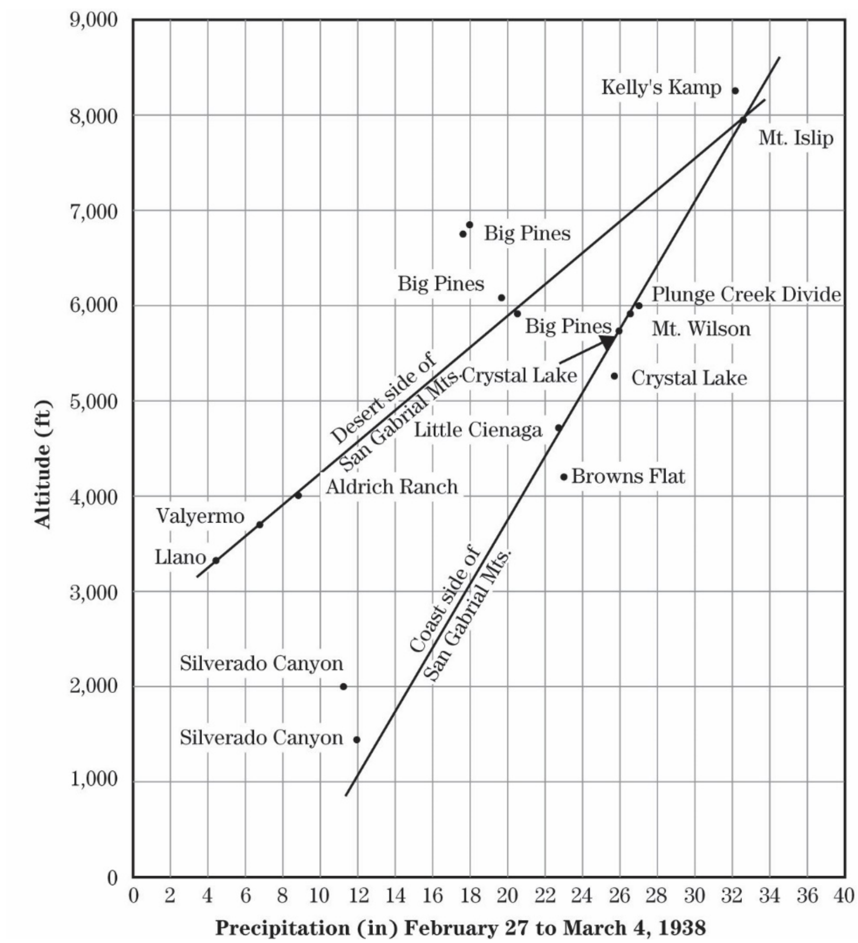
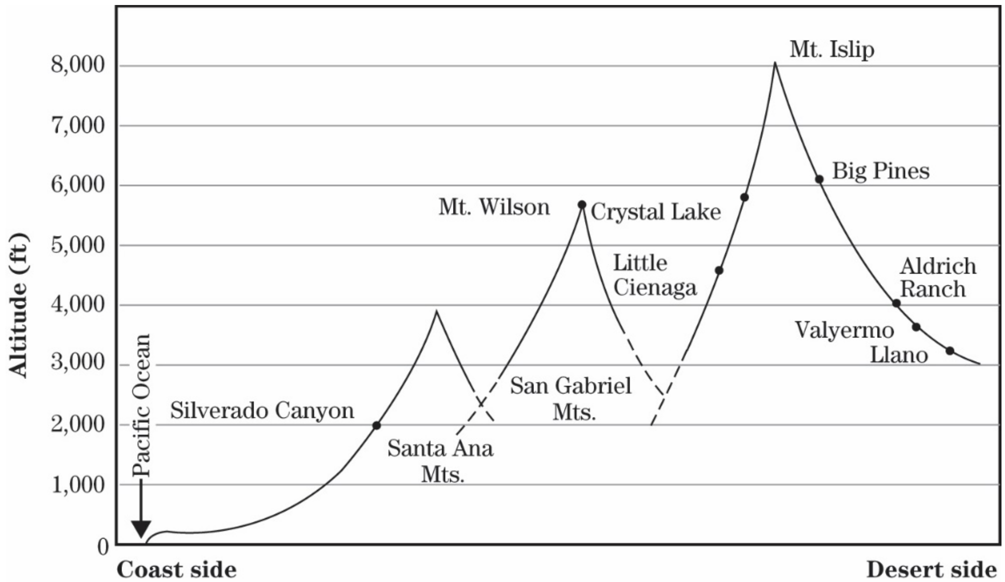


Figure 4-27: Points Denoting Gage Locations for Rain Gages in Figure 4-22.



630.0403 Temporal Distribution of Rainfall

A. Introduction

(1) Section 630.0401, "Sources of Data," describes various sources of precipitation-frequency data. These data were derived using various technical methods, for various purposes or objectives, over a period of many years. Using these data for hydrologic modeling as described in 210-NEH-630-16 and 210-NEH-630-21, requires definition of the temporal distribution of the rainfall, which is how the precipitation is distributed over time throughout a storm of a particular duration. For example, a 24-hour rainfall distribution may be defined at a time interval of 0.1 hour by the cumulative distribution of rainfall, starting at the beginning of the storm and ending at the 24-hour rainfall value.

(2) Rainfall distributions used for design of engineering projects are different from actual storms in several ways. One is that design rainfall distributions used by NRCS are generally 24 hours in duration. Actual storms have any duration from minutes up to days. Another major difference is the distribution of rainfall throughout the duration of the storm. The actual storm has variable rainfall during each increment and could even have increments of very high intensity rainfall, very low intensity rainfall, or both. The design rainfall distribution has an intensity starting low and increasing to a maximum value then gradually reducing in intensity approaching the end of the storm. A third major difference between actual storms and design storms is that even though the actual event may have a 100-year 24-hour total rainfall, the actual storm may include the 10-year 3-hour rainfall and the 5-year 5-minute rainfall (or any combination of other durations and return periods). The design rainfall distribution is developed to have the 100-year 24-hour rainfall, the 100-year 12-hour rainfall, etc., down to the 100-year 5-minute rainfall imbedded in a single storm. This paragraph is summarized in figure 4-28.

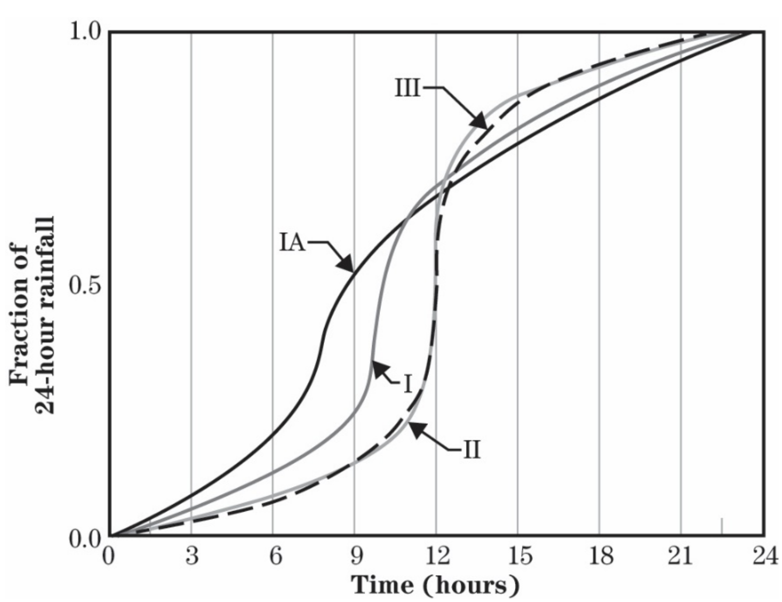
Figure 4-28: Differences Between Design Storms and Actual Storms

Storm characteristic	Design storms	Actual storms
Storm duration	24-hour duration	Any duration from minutes to days
Temporal rainfall distribution	Smoothly increasing and decreasing rainfall intensity	Irregular rainfall pattern with respect to time, possibly including intervals of no rainfall
Intensity/duration relationship	Based on intensity/duration data for a single return period such as 25-year	Generally, include intensity/duration data for different return periods

(3) Development of historical and design storm distributions are described and application guidelines and methods presented. The history of the standard NRCS storm distributions are also described. Methods for developing rainfall distributions for PMP are recommended in the various PMP documents listed in section 630.0401D. However, the concepts used in developing rainfall distributions in this chapter may be applied to develop a PMP rainfall distribution.

(4) The standard NRCS Type I and Type II synthetic rainfall distributions, used for design and planning of NRCS water-related projects, are based on Technical Paper (TP) 40 (Weather Bureau 1961a) rainfall frequency maps. The only surviving documentation concerning development of the Type I and Type II rainfall distributions is TP-149 (SCS 1973). The standard NRCS Type IA used in the Pacific Northwest was developed based on major storm cumulative rainfall distributions (Woodward 1975). The NRCS Type III distribution (Cronshey and Woodward 1989) is based on NWS Hydro-35 (NWS 1977) and TP-40 (Weather Bureau 1961a). Each of these four rainfall distributions has an intense rainfall period somewhere near the middle and lesser rainfall intensities at the beginning and end of the storm (figure 4-29). These and other standard NRCS rainfall distributions are listed and described in the WinTR-20 user documentation. The rainfall distribution tables may also be requested as WinTR-20 computer program output, which will place the tables in a file format for export to other software such as a spreadsheet or for use in other hydrologic models.

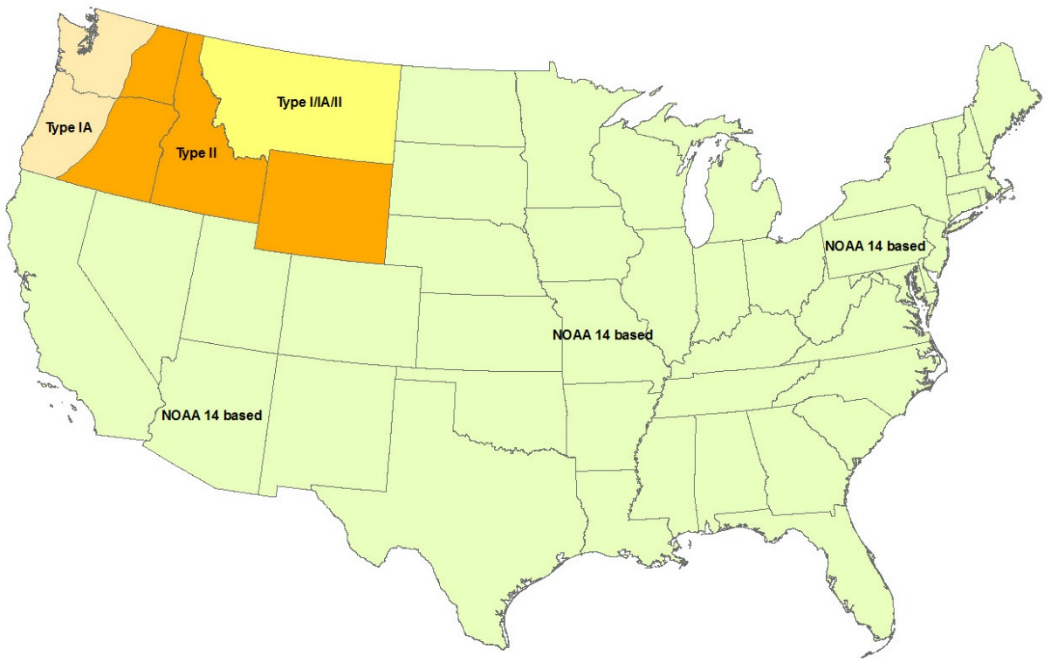
Figure 4-29: Plot of Types I, IA, II, and III Synthetic Rainfall Distributions



(5) The Type I, IA, II, and III distributions have been applied to large geographic regions. A map is included in TR-55 (SCS, 1986). For instance, the Type II distribution has been applied to a large part of the central continental Unites States.

(6) Figure 4-30 shows the current status of rainfall distribution regions within the 48 conterminous United States. NOAA Atlas 14 is complete for the southwest States, California, Ohio Valley and adjacent States, the Midwest, the southeast States, and the northeast States. NOAA Atlas 14 is also complete for Hawaii, Puerto Rico, the U.S. Virgin Islands, selected Pacific islands, and Alaska, although these are not shown in figure 4-30. Within the States where NOAA Atlas 14 is complete, the WNTSC National Water Quality and Quantity Team developed updated rainfall distributions for individual States and groups of States. Documentation of these distributions is available at the NRCS WNTSC National Water Quality and Quantity Team website http://go.usa.gov/rXYw (NRCS 2011) under "Technical Information." Documentation on use of NOAA Atlas 14 data and rainfall distributions in each individual State covered by NOAA Atlas 14 is available at the NRCS WNTSC National Water Quality and Quantity Team website under the link to the WinTR-20 model. Section 630.0408 describes development of regional rainfall distributions based on GIS data. Regional rainfall distributions were developed for California, Nevada, Midwest States, Southeast States, Ohio Valley and neighboring States, and New York and New England States.

Figure 4-30: Map of States with Updated Synthetic Rainfall Distributions as of January 2016.



(7) As the rest of the States are covered in future volumes of NOAA Atlas 14, figure 4-30 will be revised. Montana is not assigned a single distribution because the State has a procedure to select the rainfall distribution based on the ratio of 6- to 24-hour rainfall depths (SCS 1990). Any rainfall distribution developed prior to release of volumes of NOAA Atlas 14 should not be used without a specific evaluation of imbedded rainfall ratios. An important feature of a NRCS synthetic design rainfall distribution is the ratio of rain falling in a shorter duration to the total storm rainfall. For example, figure 4-31 shows that in a Type II rainfall distribution, 45.4 percent of the 24-hour storm rainfall occurs in 1 hour. In areas covered by NOAA Atlas 14, this ratio is generally different and highly site-specific. The same concept is true for other

durations such as 5, 10, 15, and 30 minutes, 2 hours, etc. To use a Type II or other legacy rainfall distribution with the updated NOAA Atlas 14 data could introduce errors by application of inaccurate rainfall intensities during the storm.

(8) Little documentation is available that describes the development of the Type II and other legacy rainfall distributions. Study of what is available leads to the conclusion that their use be discontinued in areas covered by NOAA Atlas 14 data. The Type II was assigned as the design storm distribution for much of the 48 conterminous United States. Using maps contained in TP-40, rainfall ratios for durations from 30 minutes to 12 hours divided by the 24-hour rainfall reveal significant variation from the ratios imbedded in the Type II storm distribution. In SCS Technical Paper (TP) 149 (SCS 1973), there are several locations (Alabama, Puerto Rico, Nebraska, and Utah) where the rainfall versus duration is plotted. These plots show differences at a station over 0.5 inches when compared to the Type II curve. When these legacy rainfall distributions were developed, they were developed using the best data, technology, and engineering judgment available at the time. With current data of improved quantity and quality, geographic information systems, and computer capabilities, a higher standard may be set with respect to developing and using updated rainfall distributions.

(9) An important characteristic of NRCS synthetic rainfall distributions is that the maximum rainfalls for all durations from 5 minutes to 24 hours are represented accurately. The primary assumption made in the development of the rainfall distribution is that the rainfall values for all durations for a single return period occur within one 24-hour period. For example, the 25-year 5-minute, 25-year 10-minute, 25-year 15-minute, and up to the 25-year 24-hour rainfall occurs within the same design storm and are centrally nested within each greater storm duration listed.

Figure 4-31: Ratios to 24-hour Rainfall for the Type II Distribution

Duration	Ratio to 24-hour rainfall
5 minutes	0.114
10 minutes	0.201
15 minutes	0.270
30 minutes	0.380
1 hour	0.454
2 hours	0.538
3 hours	0.595
6 hours	0.707
12 hours	0.841
24 hours	1.00

B. Precipitation-Frequency Data Ratio Analyses

(1) The foundation of rainfall distributions as used throughout the history of NRCS is the set of ratios of the shorter durations to the 24-hour rainfall. The ratios of 5-minute through 12-hour rainfall to the 24-hour rainfall imbedded in the Type II distribution are included in figure 4-31 as an example. NOAA Atlas 14 data for the desert southwest (NOAA Atlas 14, Volume 1) and Ohio Valley and neighboring States (NOAA Atlas 14, Volume 2) were analyzed with respect to ratios of shorter durations to the 24-hour rainfall values at many point locations (Merkel et al. 2006).

(2) Section 630.0405 contains an example which compares the Type II distribution with the original TP-40 and Hydro-35 rainfall values. The ratios of shorter duration to the 24-hour rainfall developed with data from TP-40 and Hydro-35 are compared with ratios from the

standard Type II distribution, which has been used there in the past. Columbus, OH, is the location that was evaluated.

(3) The ratios for each duration to the 24-hour rainfall that are imbedded in the standard Type II rainfall distribution as shown in figure 4-31. Variability of ratios is also evident in rainfall distributions based on the NOAA Atlas 14 data. The engineer must determine how much difference between the site-specific distribution and the regional rainfall distribution is acceptable for each specific project.

(4) To summarize the results of the analyses, the ratios of shorter duration to the 24-hour rainfall varied both spatially and by return period enough to conclude that the ratios imbedded in the standard NRCS rainfall distributions (Types I, IA, II, and III) are not consistent with ratios developed from NOAA Atlas 14 rainfall values. Rainfall distributions, which cover large geographic regions, may have large variation of ratios that could lead to overestimation or underestimation of peak discharge when used with a hydrologic model such as WinTR-20 or WinTR-55. Overestimation and underestimation refers to the difference between using the regional rainfall distribution and the site-specific rainfall distribution based on the return period being analyzed. However, a properly designed rainfall distribution, such as demonstrated in section 630.0408 of this chapter, may be feasible if ratio limits are set and tests are made to ensure the maximum range in peak discharge values is within an appropriate tolerance.

(5) To illustrate the variation of rainfall distribution with return period and sensitivity of peak discharge, the Wilmington Airport, NC, station was selected. The partial duration precipitation values were downloaded and the ratios of 5-minute 24-hour through 12-hour 24-hour ratios were computed and plotted in figure 4-32. The ratios for the 1- through 500-year return periods are compared with the ratios imbedded within the standard Types I, II, and III rainfall distributions.

(6) The figure shows that the Type II ratios are an approximate upper limit, which falls close to the 1-year ratios. The Type III ratios fall in the mid-range of the return periods (25- and 50-year). The Type I ratios are an approximate lower limit for the 500-year ratios up to about 30-minute duration. The ratios show that it may be inappropriate to use a single rainfall distribution for all return periods. However, depending on the project purpose and complexity, using a single rainfall distribution to represent a design storm may be appropriate.

(7) The ratios of shorter duration to the 24-hour duration may have a significant impact on peak discharges of hydrographs generated using the particular rainfall distribution. Considering the storms from 1-year through 100-years, the ratios for the 10-year storm shown in figure 4-32 represent the average for this location. For this example, rainfall distributions for each return period were developed based on ratios of the 5-minute to 24-hour through 12-hour to 24-hour ratios. The expected difference in peak discharge based on an individual rainfall distribution for each return period versus the average for all return periods from 1-year through 100-years varies by location and by runoff curve number and time of concentration. WinTR-20 was run for a runoff curve number of 75 and times of concentration (Tc) of 0.5 and 1.0 hour. A drainage area of 0.5 square mile was used. However, when only interested in percentage difference of peak discharge, the drainage area is immaterial. The percent differences are shown in figure 4-33.

(8) Positive differences in figure 4-33 indicate the peak discharge is greater with the individual return period rainfall distribution when compared to the average rainfall distribution. Negative differences indicate the peak discharge is less with the individual return period rainfall distribution when compared to the average rainfall distribution. The results in figure 4-33 show what is expected when considering the plot of ratios in figure 4-32. Ratios for the 1-year, 2-year and 5-year storms are greater than ratios for the 10-year return period and the higher peak discharges for those storms reflect that.

(9) Wilmington, NC, is a somewhat extreme example of ratio variation by return period. Many other locations have a narrower range of variation. However, if this variation is evident anywhere, it leads to the conclusion that new rainfall distributions are needed to replace the legacy rainfall distribution types.

Figure 4-32: Ratios of 5-Minute 24-Hour through 12-Hour 24-Hour Ratios for Different Distributions, Data for Wilmington Airport, NC

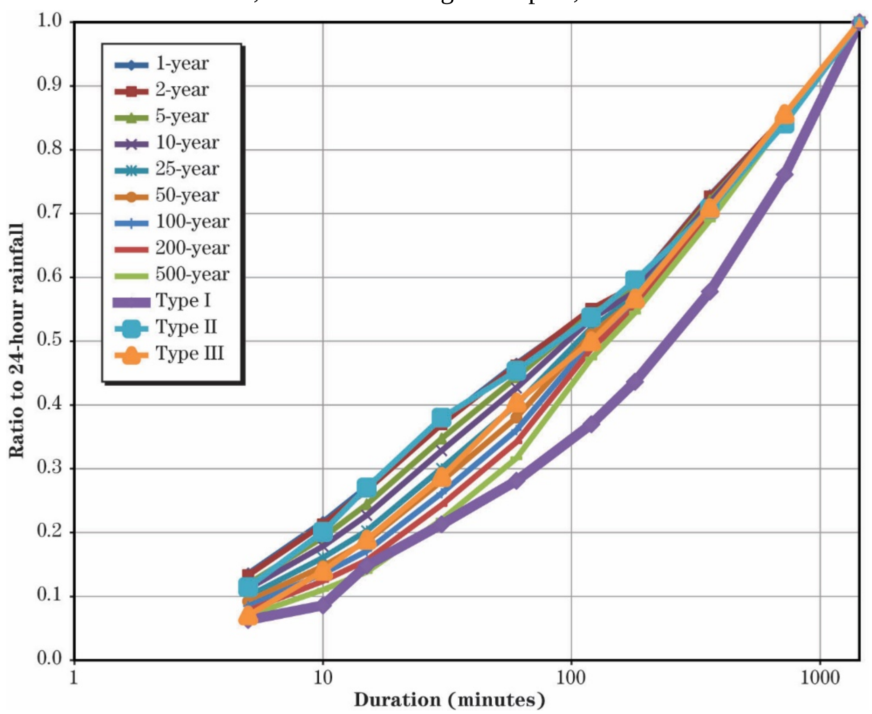


Figure 4-33: Percent Difference in Peak Discharge Using Individual Storm Rainfall Distributions Versus an Average Rainfall Distribution for Wilmington, NC

Storm return period, years	Percent difference Tc = 0.5 hour	Percent difference Tc = 1.0 hour
1	14.5	9.8
2	13.0	9.4
5	5.2	4.3
10	0.0	0.0
25	–8.3	–6.2
50	–14.6	–11.6
100	–20.0	–16.2

C. Development of Synthetic Rainfall Distributions

(1) Merkel et al. (Merkel 2006 and Merkel et al. 2015) developed a procedure to derive rainfall distributions to cover the wide range of climatic conditions from tropical to arctic that occur in the United States.

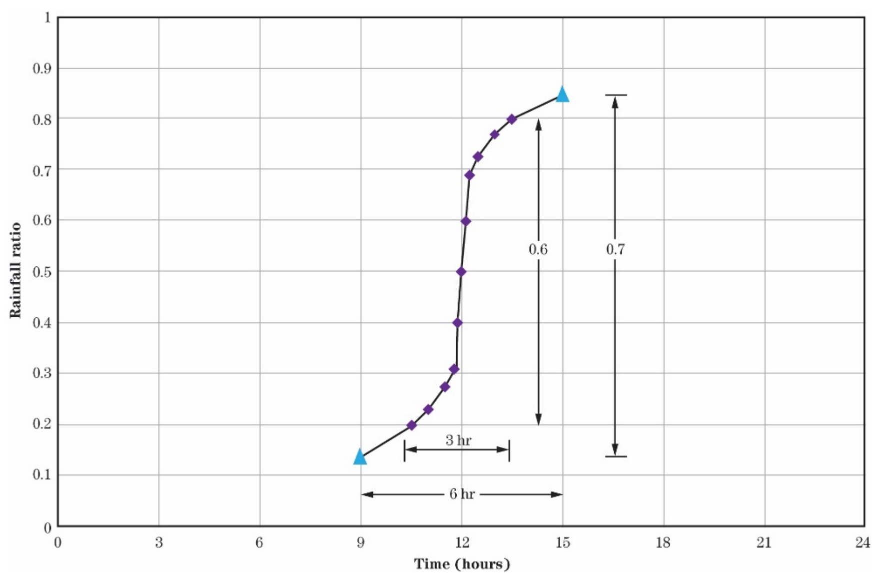
(2) The method used to construct the 24-hour rainfall distribution ensures that the maximum rainfall of any duration less than 24 hours is included in the distribution. It is one of the

principles of hydrology that the peak discharge for a watershed is determined primarily by rain falling in a duration, which equals the time of concentration (210-NEH-630-15 (NRCS 2010b)). The 24-hour rainfall distribution has the maximum 5-minute rainfall occurring from 12 to 12.1 hours. The maximum 10-minute rainfall is between 11.9 and 12.1 hours, and includes the maximum 5-minute rainfall, and so on. Since the rainfall distribution is developed at a 0.1-hour (6-mins.) time interval, the values at 0.1-hour time interval are interpolated from the 5, 10, 15 and 30-minute rainfall values. In this way, a single rainfall distribution for 24 hours may be used for any watershed with time of concentration less than 24 hours.

(3) In many investigations of precipitation-frequency data from NOAA Atlas 14 a number of geographic regions have a relationship of precipitation intensity versus duration, which is not smooth. When the precipitation intensity-duration relationship is not smooth, the resulting rainfall distribution is not smooth. Section 630.0406 describes these situations and how the data may be smoothed to generate a smooth rainfall distribution. Software associated with WinTR-20 automates this data smoothing option.

(4) In figure 4-34, the ratio of 3-hour to 24-hour rainfall is 0.6. The 3-hour duration is centered on 12 hours, so the 3-hour period will start at 10.5 hours and end at 13.5 hours. The ratio value of 0.6 is centered at 0.5 so the cumulative rain ratio for the 3-hour duration begins at 0.2 and ends at 0.8. The ratio of 6-hour to 24-hour rainfall is 0.7. The 6-hour duration is centered on 12 hours, so the 6-hour period will start at 9 hours and end at 15 hours. The ratio value of 0.7 is centered at 0.5 so the cumulative rain ratio for the 6-hour duration begins at 0.15 and ends at 0.85. All durations from 1 hour to 12 hours are treated similarly as the 3-hour and 6-hour durations explained above. Since the rainfall table is developed at a 0.1-hour time interval, cumulative rainfall ratios from 11.6 hours to 12.4 hours are interpolated based on ratios of 5-minute, 10-minute, 15-minute, and 30-minute to 24-hour rainfall. A curve is fit to pass through the ratio points developed from the procedure described above to make a smooth cumulative rainfall distribution, which gradually increases in rainfall intensity from zero to 12 hours and gradually decreases in rainfall intensity from 12 hours to 24 hours. Section 630.0407 describes the procedure in detail.

Figure 4-34: Construction of Rainfall Distribution from Precipitation versus Duration Data



(5) Since the 24-hour design rainfall distribution is built to include the maximum rainfall distribution for any shorter duration, the rainfall distribution for any duration may be extracted from it. An example follows.

(6) **Example 4-5.**—Extract a 6-hour rainfall distribution from the 24-hour rainfall distribution at a location in Bradford County, FL, using data from NOAA Atlas 14. The table of 24-hour cumulative rainfalls at an increment of 0.5 hour is in figure 4-35, columns 1 and 2. A time increment of 0.5 hour is used to shorten the example and still demonstrate the concepts. The maximum 6 hours of the 24-hour rainfall distribution is from 12 hours plus and minus 3 hours or from 9 to 15 hours. The cumulative value at 9 hours is 0.1108 and at 15 hours is 0.8892 and the difference is 0.7784. Values in column 3 are values in column 2 with 0.1108 (value at 9 hours) subtracted from each. Values in column 4 are the cumulative values of time for the 6-hour rainfall distribution (beginning at 0.0 and ending at 6.0 hours). The values in column 5 are the values in column 3 divided by 0.7784 (difference between 9 and 15 hours). Thus, columns 4 and 5 represent the 6-hour rainfall distribution. The 6-hour rainfall distribution starts at a cumulative value of 0.0 and ends at a cumulative value of 1.0.

(7) Why does NRCS use primarily the 24-hour rainfall distribution? When NRCS originally developed hydrologic procedures in the 1950s, most rain gages recorded daily (24-hour) rainfall. Few recorded hourly and sub hourly values and there was much more confidence in the daily records and associated rainfall frequency analyses. Hourly and sub hourly measurements were used to distribute the rainfall within the 24-hour duration storm. With only two original rainfall distributions, the Type I and Type II (SCS-TP-149), tables and graphs for hydrologic analyses could be developed easily. Users of the hydrologic procedures needed only a 24-hour rainfall value along with basic watershed data to complete a hydrologic analysis.

(8) Rainfall and runoff data used to develop runoff curve numbers are a combination of storm event rainfall and runoff and daily rainfall and runoff. The word daily is interpreted as being 24 hours. In NRCS hydrologic procedures, the curve number is applied to estimate the 24-hour runoff volume based on the 24-hour rainfall. The 24-hour rainfall distribution includes the maximum rainfall distribution for all shorter durations. By using rainfall values for all durations from 5 minutes to 24 hours to develop the rainfall distribution and nesting the durations, a maximized rainfall distribution results. This will ensure that the maximum rainfall intensity is applied to a watershed with any time of concentration less than 24 hours. In modernizing NRCS hydrologic procedures, the number of rainfall distributions has increased greatly, though standard use of the 24-hour duration is continued. Development of the rainfall distribution is automated in WinTR-20, allowing for use of both regional and site-specific rainfall distributions

Figure 4-35: Six-Hour Rainfall Distribution Extracted from a 24-Hour Rainfall Distribution

Time (hr)	Cumulative 24-hr rainfall ratio	Unadjusted cumulative 6-hr rainfall ratio	6-hr distribution time (hr)	6-hr distribution cumulative rainfall ratio
(1)	(2)	(3)	(4)	(5)
0	0.0000			
0.5	0.0031			
1	0.0064			
1.5	0.0100			
2	0.0139			
2.5	0.0180			
3	0.0224			
3.5	0.0271			
4	0.0320			
4.5	0.0372			
5	0.0427			
5.5	0.0484			
6	0.0544			
6.5	0.0612			
7	0.0690			
7.5	0.0778			
8	0.0878			
8.5	0.0988			
9	0.1108	0.0000	0	0.0000
9.5	0.1259	0.0151	0.5	0.0194
10	0.1454	0.0346	1	0.0445
10.5	0.1693	0.0585	1.5	0.0751
11	0.2057	0.0949	2	0.1219
11.5	0.2712	0.1604	2.5	0.2061
12	0.4763	0.3655	3	0.4696
12.5	0.7288	0.6180	3.5	0.7939
13	0.7943	0.6835	4	0.8781
13.5	0.8307	0.7199	4.5	0.9249
14	0.8546	0.7438	5	0.9555
14.5	0.8741	0.7633	5.5	0.9806
15	0.8892	0.7784	6	1.0000
15.5	0.9013			
16	0.9122			
16.5	0.9222			
17	0.9310			
17.5	0.9388			
18	0.9456			
18.5	0.9516			
19	0.9573			
19.5	0.9628			
20	0.9680			
20.5	0.9729			
21	0.9776			
21.5	0.9820			
22	0.9861			
22.5	0.9900			
23	0.9936			
23.5	0.9969			
24	1.0000			

D. Development of a Rainfall Distribution for a Historical Storm

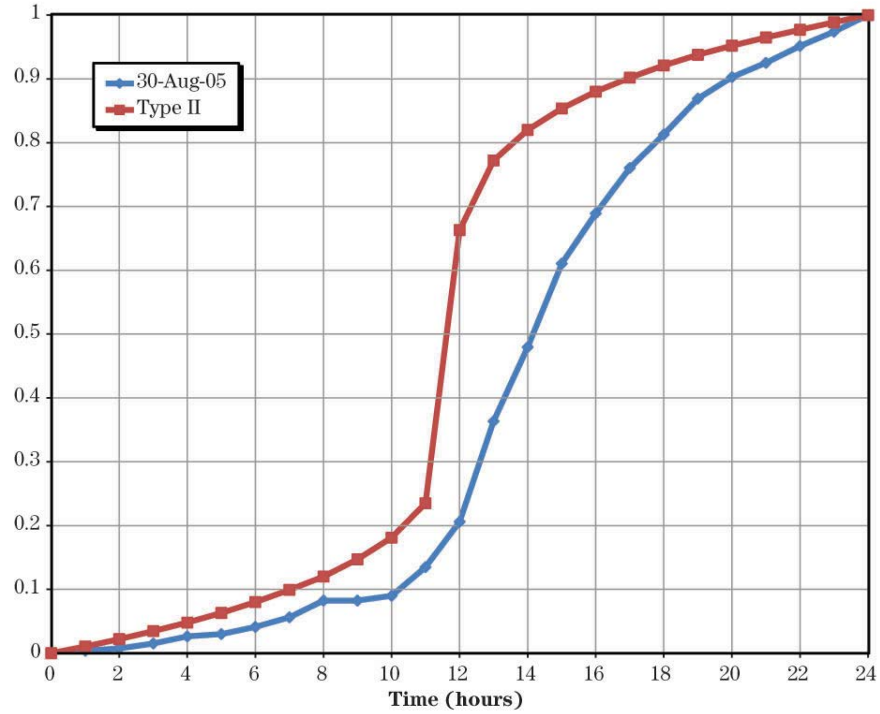
(1) One purpose for developing a rainfall distribution for a historical storm is to run a hydrologic model such as WinTR-20 or WinTR-55 for a watershed to validate the model data or conduct a storm assessment comparing the model results to actual flood data such as a peak discharge, flood hydrograph, or high-water marks. This example uses the storm of August 30, 2005, at Columbus, OH. From records of the National Weather Service, the actual time and hourly precipitation data are shown in columns 1 and 3 of figure 4-36.

(2) The hourly values are accumulated from the beginning to the end of the storm in column 4 of figure 4-36. The ratios of the accumulated precipitation to the total storm precipitation are shown in column 5. For comparison, the ratios for the Type II storm distribution are shown in column 6. The cumulative rain ratios for the actual storm event and the Type II are shown in figure 4-37. The storm of August 30, 2005, has the same general shape as the Type II distribution, starting with low rainfall intensity at the beginning of the storm, higher intensity in the middle and lower intensity near the end. Actual storm distributions, which may be front-loaded or end-loaded, may plot anywhere within a graph similar to figure 4-37. Even though the Type II is a hypothetical storm, actual storms may approach the Type II storm distribution with respect to general shape and maximum rainfall intensity.

Figure 4-36: Hourly Rainfall Data and Distribution at Columbus, OH, August 30, 2005

Actual time, hours	Time from beginning of storm, hours	Hourly precipitation, inches	Accumulated precipitation, inches	Accumulated ratio (col. 3/col. 4)	Type II storm ratio
(1)	(2)	(3)	(4)	(5)	(6)
4 a.m.	0	0	0	0	0
5	1	0.01	0.01	0.004	0.011
6	2	0.01	0.02	0.007	0.022
7	3	0.02	0.04	0.015	0.035
8	4	0.03	0.07	0.026	0.048
9	5	0.01	0.08	0.030	0.063
10	6	0.03	0.11	0.041	0.080
11	7	0.04	0.15	0.056	0.099
12 Noon	8	0.07	0.22	0.082	0.120
1	9	0.0	0.22	0.082	0.147
2	10	0.02	0.24	0.090	0.181
3	11	0.12	0.36	0.135	0.235
4	12	0.19	0.55	0.206	0.663
5	13	0.42	0.97	0.363	0.772
6	14	0.31	1.28	0.479	0.820
7	15	0.35	1.63	0.610	0.854
8	16	0.21	1.84	0.689	0.880
9	17	0.19	2.03	0.760	0.902
10	18	0.14	2.17	0.813	0.921
11	19	0.15	2.32	0.869	0.938
12 Midnight	20	0.09	2.41	0.903	0.952
1	21	0.06	2.47	0.925	0.965
2	22	0.07	2.54	0.951	0.977
3	23	0.06	2.6	0.974	0.989
4	24	0.07	2.67	1.000	1.000

Figure 4-37: Construction of Rainfall Distribution from Precipitation versus Duration Data



630.0404 Uses of Precipitation Depth and Distribution

A. Average storm rainfall is sometimes used in hydrologic models, such as WinTR-20 and WinTR-55, to estimate the peak discharge for a particular storm event. Another possible application is to use average watershed rainfall along with measured runoff volume to determine a calibrated watershed runoff curve number for a particular storm event. An estimation of mean annual precipitation may be needed for other purposes such as application of USGS peak discharge equations when the mean annual precipitation is a regression variable or relating the mean annual precipitation value to other hydrologic data such as volume of runoff.

B. The WinTR-20 hydrologic model could be used to analyze the effects of the 25-year 24-hour and other storms on a watershed. The EFH-2 program has the limitation of using only a single watershed and WinTR-55, though it may analyze a watershed with subareas, has the limitation of using a uniform rainfall over the entire watershed.

C. An actual storm distribution may be used in WinTR-20 or WinTR-55 to estimate peak discharges and hydrographs for a watershed impacted by a particular storm event in order to assess damages as a result of this storm or to calibrate other data. Calibration involves verifying the proper assignment of the various hydrologic model input parameters such as watershed area, runoff curve number, time of concentration, and dimensionless unit hydrograph peak rate factor. Once a hydrologic model is calibrated, hypothetical, synthetic, and design rainfall depths and distributions may be analyzed with the hydrologic model to estimate impacts of flood events. This can be done with confidence based on comparing the hydrologic model results to actual rainfall and runoff gages for multiple storms.

D. NRCS models such as WinTR-20, WinTR-55, SITES, and EFH-2 are designed to use standardized rainfall distributions. A custom rainfall distribution may be used instead of one of the standard rainfall distributions in WinTR-20, WinTR-55, and SITES. This custom rainfall distribution may be based on an historical or actual storm event or based on NOAA Atlas 14 data at the project location.

630.0405 Comparing Precipitation-Frequency Data and Distribution

A. This section explains and shows, through tables and calculations, how to compare rainfall magnitude and rainfall distribution from an older rainfall atlas - such as Technical Paper No. 40 (TP-40) (Weather Bureau 1961a) or NOAA Atlas 2 (NWS 1973) - with data from NOAA Atlas 14 (NWS 2005) for a particular location.

B. This example, using the data for Columbus, OH, illustrates an example of the comparison between old and new rainfall-frequency data and rainfall distributions.

C. Comparing Rainfall Distribution Based on NWS Hydro 35 and TP–40 to the NRCS Type II

(1) Figure 4-38 lists the partial duration precipitation values in inches for Columbus, OH, derived from maps in NOAA Technical Memorandum NWS Hydro 35 (NWS 1977) by frequency. NWS Hydro 35 includes only data from 5 through 60 minutes.

(2) Figure 4-39 lists the partial duration precipitation values in inches for Columbus, OH, derived from maps in TP–40 (Weather Bureau 1961a) by frequency. TP–40 includes data only from 0.5 through 24 hours.

(3) Ratios of shorter duration to the 24-hour rainfall are shown in figure 4-40. For example, the ratio for the 10-year, 1-hour rainfall is 1.8 inches divided by 3.8 inches (both values from figure 4-39) or 0.474.

(4) There is overlap of data between figures 4-38 and 4-39 for 30 and 60 minutes (0.5 and 1 hr). TP–40 values for 0.5 and 1 hour are used to compute ratios in figure 4-40 because the plot of ratio versus duration is relatively smooth as shown in figure 4-41. If NWS Hydro 35 ratios had been used, there would be a sharp change of slope in the curves between 1 and 2 hours.

(5) Figure 4-41 is a plot of the values in figure 4-40. The plotted curves show significant variation of ratios among return periods, which are equal or greater than the ratios of the NRCS Type II rainfall distribution.

(6) The NWS Hydro 35 ratio is plotted for 5 to 15 minutes. The TP–40 ratio is plotted for 30-minute to 24-hour durations.

(7) Just as a rainfall distribution may be built based on ratios of 5-minute to 24-hour rainfall through 12-hour to 24-hour rainfall, ratios of these shorter durations to the 24-hour may be extracted from an existing rainfall distribution. Column 3 of figure 4-42 includes ratios of shorter duration to the 24-hour total extracted from the NRCS Type II rainfall distribution.

(8) These analyses compare the NRCS Type II distribution to Hydro–35 and TP–40 data. A rainfall distribution developed from Hydro–35 and TP–40 for Columbus, OH, would produce higher peak discharges than the NRCS Type II because the ratios for durations from 5 minutes to 12 hours are higher for Hydro–35 and TP–40 data. Based on the ratios in figure 4-42, the percentage increase in peak discharge differs for the various return periods.

Figure 4-38: Precipitation – Frequency for Columbus, OH, Hydro 35

Duration (min)	2-yr (in)	5-yr (in)	10-yr (in)	25-yr (in)	50-yr (in)	100-yr (in)
5	0.43	0.49	0.55	0.63	0.69	0.75
10	0.66	0.79	0.89	1.03	1.15	1.26
15	0.82	1.00	1.13	1.32	1.46	1.61
30	1.06	1.33	1.52	1.79	2.01	2.22
60	1.30	1.67	1.92	2.29	2.57	2.85

Figure 4-39: Precipitation – Frequency for Columbus, OH, TP-40

Duration (hr)	2-yr (in)	5-yr (in)	10-yr (in)	25-yr (in)	50-yr (in)	100-yr (in)
0.5	1.02	1.28	1.48	1.7	1.9	2.1
1	1.26	1.6	1.8	2.15	2.4	2.7
2	1.52	1.9	2.25	2.5	2.85	3.1
3	1.65	2	2.4	2.8	3	3.4
6	1.95	2.45	2.9	3.25	3.7	3.9
12	2.35	2.9	3.35	3.75	4	4.75
24	2.6	3.3	3.8	4.3	4.7	5

Figure 4-40: Ratio of Shorter Duration to 24-hour Precipitation for Columbus, OH [1/] (Hydro 35 and TP-40)

Duration (minutes or hours)	2-year	5-year	10-year	25-year	50-year	100-year
5-min Hydro 35 [1/]	0.165	0.148	0.145	0.147	0.147	0.150
10-min Hydro 35 [1/]	0.254	0.239	0.234	0.240	0.245	0.252
15-min Hydro 35 [1/]	0.315	0.303	0.297	0.307	0.311	0.322
30-min TP-40	0.392	0.388	0.389	0.395	0.404	0.420
1-hr TP-40	0.585	0.579	0.592	0.581	0.606	0.620
3-hr TP-40	0.635	0.606	0.632	0.651	0.638	0.680
6-hr TP-40	0.750	0.742	0.763	0.756	0.787	0.780
12-hr TP-40	0.904	0.879	0.882	0.872	0.851	0.950
24-hr TP-40	1.000	1.000	1.000	1.000	1.000	1.000

[1/] Ratios equal 5 to 15-minute values from figure 4-38 over 24-hour values from figure 4-39 and 30-min to 24-hour values from figure 4-39 over 24-hour values from figure 4-39.

Figure 4-41: Plot of Ratios of Shorter Duration to the 24-Hour Precipitation for Columbus, OH

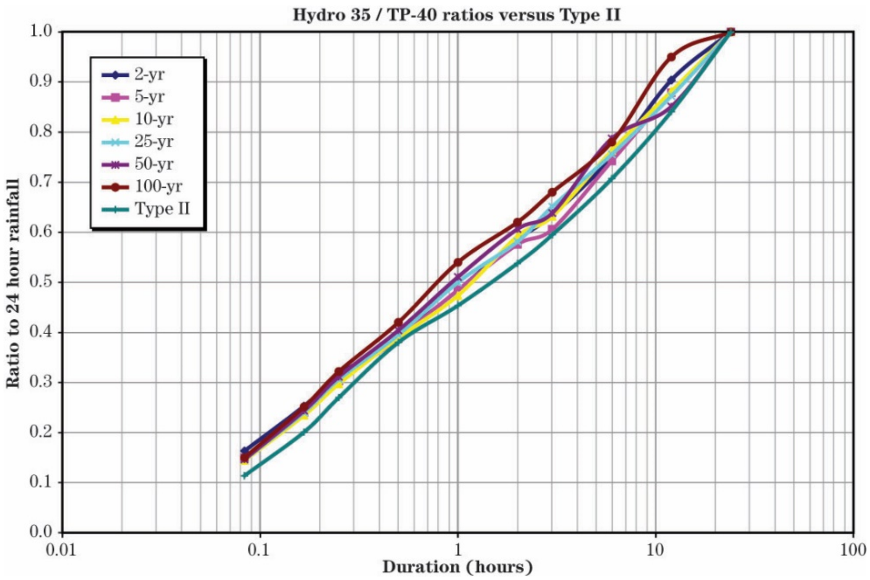


Figure 4-42: Comparison of Ratios for Columbus, OH (Hydro 35 and TP-40) and the Type II Ratio for all Durations

Duration (minutes or hours)	**Columbus, OH, average ratio [1/]**	**Type II ratio**	**Average percent difference in ratio [2/]**	**Largest percent difference for any return period [3/]**
(1)	**(2)**	**(3)**	**(4)**	**(5)**
5-min Hydro 35 [1/]	0.150	0.114	31.58	44.74
10-min Hydro 35 [1/]	0.244	0.201	21.39	26.37
15-min Hydro 35 [1/]	0.309	0.270	14.44	19.26
30-min TP-40	0.398	0.380	4.74	10.53
1-hr TP-40	0.499	0.454	9.91	18.9
2-hr TP-40	0.593	0.538	10.22	15.24
3-hr TP-40	0.640	0.595	7.56	14.29
6-hr TP-40	0.763	0.707	7.92	11.32
12-hr TP-40	0.890	0.841	5.83	12.96
24-hr TP-40	1.000	1.000	1.000	1.000

[1/] col. 2 = average of all frequencies for each duration, figure 4-40
[2/] col. 4 = [(col. 2 – col. 3) / col.3] x 100
[3/] col. 5 = [(largest ratio for duration in figure 4-40 - col. 3) / col. 3] x 100

D. Comparing Rainfall Distribution Based on NOAA Atlas 14 to the NRCS Type II

(1) Figure 4-43 shows partial duration data downloaded from the NOAA-NWS website for NOAA Atlas 14 for Columbus, OH, at the WSO Airport (latitude 39.9914 N and longitude 82.8808 W). Partial duration data were downloaded because NRCS typically uses that for design of engineering projects.

(2) The 90-percent confidence limits are shown in parentheses for each duration and frequency in the table.

(3) The probability is 90 percent that the actual value will fall within that range.

(4) Figure 4-44 lists ratios of shorter duration to the 24-hour duration rainfall based on values from figure 4-43. For example, the ratio of 2-year, 5-minute to 2-year, 24-hour rainfall is 0.421/2.62 or 0.161.

(5) Ratios for 5 through 30 minutes decrease from the 2- to 100-year values. Ratios for the 1- through 3-hour durations are relatively constant. Ratios for 6- and 12-hour durations increase from the 2- to 100-year values. This leads to slightly different rainfall distributions for each of the return periods.

(6) Figure 4-45 plots the ratios. These analyses compare the NRCS Type II distribution to NOAA Atlas 14 data. A rainfall distribution developed from NOAA Atlas 14 data for Columbus, OH, would produce higher peak discharges than the NRCS Type II because the ratios for durations from 5 minutes to 12 hours are higher for NOAA Atlas 14 data. Based on the ratios in figure 4-46, the percentage increase in peak discharge differs for the various return periods and time of concentration.

Figure 4-43: NOAA Atlas 14 Partial Duration Series (PDS) Precipitation-Frequency Data for Columbus, OH

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]									
Duration	Average recurrence interval (years)								
	1	2	5	10	25	50	100	200	500
5-min	0.353 (0.322–0.387)	0.421 (0.384–0.462)	0.504 (0.459–0.553)	0.569 (0.517–0.623)	0.652 (0.589–0.713)	0.715 (0.644–0.780)	0.778 (0.696–0.848)	0.842 (0.749–0.918)	0.927 (0.818–1.01)
10-min	0.548 (0.500–0.602)	0.657 (0.600–0.721)	0.784 (0.713–0.860)	0.879 (0.799–0.961)	0.997 (0.900–1.09)	1.09 (0.976–1.18)	1.17 (1.05–1.28)	1.26 (1.12–1.37)	1.36 (1.20–1.49)
15-min	0.672 (0.613–0.738)	0.803 (0.733–0.882)	0.962 (0.875–1.06)	1.08 (0.983–1.18)	1.23 (1.11–1.35)	1.34 (1.21–1.46)	1.46 (1.30–1.59)	1.56 (1.39–1.70)	1.70 (1.50–1.85)
30-min	0.889 (0.811–0.976)	1.08 (0.981–1.18)	1.32 (1.20–1.45)	1.50 (1.36–1.64)	1.74 (1.57–1.90)	1.92 (1.73–2.09)	2.10 (1.88–2.29)	2.28 (2.03–2.49)	2.52 (2.22–2.75)
60-min	1.09 (0.990–1.19)	1.32 (1.20–1.45)	1.65 (1.50–1.81)	1.91 (1.74–2.09)	2.26 (2.04–2.47)	2.53 (2.28–2.76)	2.81 (2.51–3.06)	3.10 (2.75–3.38)	3.49 (3.08–3.80)
2-hr	1.27 (1.16–1.39)	1.54 (1.41–1.68)	1.93 (1.76–2.11)	2.24 (2.04–2.45)	2.67 (2.42–2.92)	3.02 (2.72–3.30)	3.39 (3.03–3.69)	3.77 (3.35–4.10)	4.30 (3.79–4.67)
3-hr	1.35 (1.23–1.48)	1.63 (1.49–1.78)	2.04 (1.86–2.23)	2.37 (2.16–2.58)	2.84 (2.57–3.09)	3.21 (2.90–3.49)	3.61 (3.24–3.92)	4.03 (3.59–4.37)	4.62 (4.07–5.01)
6-hr	1.61 (1.48–1.76)	1.94 (1.78–2.12)	2.41 (2.20–2.63)	2.80 (2.56–3.05)	3.36 (3.05–3.65)	3.83 (3.45–4.15)	4.33 (3.88–4.68)	4.86 (4.32–5.24)	5.62 (4.93–6.07)
12-hr	1.89 (1.73–2.07)	2.26 (2.07–2.48)	2.80 (2.56–3.07)	3.25 (2.96–3.56)	3.90 (3.54–4.25)	4.44 (4.00–4.83)	5.03 (4.49–5.45)	5.65 (5.01–6.11)	6.55 (5.72–7.09)
24-hr	2.20 (2.04–2.37)	2.62 (2.44–2.84)	3.23 (3.00–3.49)	3.73 (3.46–4.02)	4.44 (4.09–4.79)	5.03 (4.61–5.42)	5.65 (5.15–6.09)	6.30 (5.71–6.80)	7.23 (6.48–7.81)

Figure 4-44: Ratio of Shorter Duration to 24-hour Precipitation for Columbus, OH (Based on NOAA Atlas 14 Data)

Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5-min	0.161	0.156	0.153	0.147	0.142	0.138
10-min	0.251	0.243	0.236	0.225	0.217	0.207
15-min	0.306	0.298	0.290	0.277	0.266	0.259
30-min	0.412	0.409	0.402	0.392	0.382	0.372
1-hr	0.504	0.511	0.512	0.509	0.503	0.498
2-hr	0.588	0.598	0.601	0.601	0.600	0.601
3-hr	0.622	0.632	0.635	0.640	0.638	0.640
6-hr	0.740	0.746	0.751	0.757	0.761	0.768
12-hr	0.863	0.867	0.871	0.878	0.883	0.892
24-hr	1.000	1.000	1.000	1.000	1.000	1.000

Figure 4-45: Plot of Ratios of Shorter Duration to the 24-Hour Precipitation for Columbus, OH

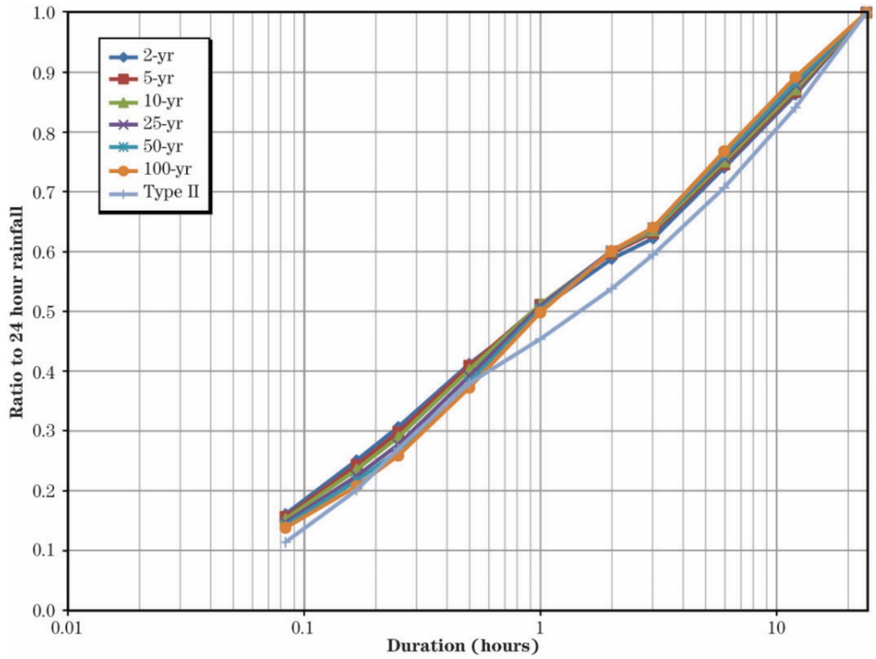


Figure 4-46: Comparison of Ratios for Columbus, OH (NOAA Atlas 14) and the Type II Ratio for All Durations

Duration	Columbus, OH, average ratio of NOAA Atlas 14 data [1/]	Type II ratio	Average percent difference in ratio[2/]	Largest percent difference for any return period[3/]
(1)	(2)	(3)	(4)	(5)
5-min	0.149	0.114	31.02	40.95
10-min	0.230	0.201	14.25	24.76
15-min	0.283	0.270	4.70	13.51
30-min	0.395	0.380	3.90	7.54
1-hour	0.506	0.454	11.56	12.86
2-hour	0.598	0.538	11.17	11.72
3-hour	0.634	0.595	6.64	7.57
6-hour	0.754	0.707	6.63	8.59
12-hour	0.876	0.841	4.12	6.05
24-hour	1.000	1.000	0.00	0.00

[1/] col. 2 = average of all frequencies for each duration
[2/] col. 4 = [(col. 2 – col. 3) / col. 3] x 100
[3/] col. 5 = [(largest ratio for duration in figure 4-44 – col. 3) / col. 3] x 100

E. Comparing Rainfall Data of NOAA Atlas 14 with NWS Hydro 35 and TP–40

(1) Figure 4-47 shows the comparison of NOAA Atlas 14 data and NWS Hydro 35 and TP–40 for Columbus OH.

(2) Figure 4-50 uses values of NWS Hydro 35 for the 5 through 15 minutes of figure 4-38 and TP–40 rainfalls for 30 through 24 hours from figure 4-39, respectively, subtracted from the NOAA Atlas 14 rainfall values in figure 4-43. A positive difference means that NOAA Atlas

14 rainfall is higher. The differences for 2 to 10 years are relatively small. NOAA Atlas 14 has larger precipitation for the 25- to 100-year 1- to 24-hour durations.

Figure 4-47: Difference between NOAA Atlas 14 and Hydro 35 / TP-40 Rainfall for Columbus, OH

Duration	2-yr Difference (in)	5-yr Difference (in)	10-yr Difference (in)	25-yr Difference (in)	50-yr Difference (in)	100-yr Difference (in)
5-min Hydro 35	– 0.01	0.01	0.02	0.02	0.02	0.03
0-min	0.00	0.00	-0.01	– 0.03	– 0.06	– 0.09
15-min	– 0.02	– 0.04	– 0.05	– 0.09	– 0.12	– 0.15
30-min TP-40	0.06	0.04	0.02	0.04	0.02	0.00
1-hr	0.06	0.05	0.11	0.11	0.13	0.11
2-hr	0.02	0.03	– 0.01	0.17	0.17	0.29
3-hr	– 0.02	0.04	– 0.03	0.04	0.21	0.21
6-hr	– 0.01	– 0.04	– 0.10	0.11	0.13	0.43
12-hr	– 0.09	– 0.10	– 0.10	0.15	0.44	0.28
24-hr	0.02	– 0.07	– 0.07	0.14	0.33	0.65

F. Summary

Precipitation-frequency data and storm distribution are important components of the NRCS hydrologic modeling procedures. Different assumptions and procedures were used in preparation of precipitation frequency atlases TP–40 and NOAA Atlas 14 by the NWS and in preparation of storm distributions NRCS Type II and those based on NOAA Atlas 14 data. Understanding these differences will provide more background on why hydrologic results could be different when changing from TP–40 and the Type I, IA, II, or III storm distribution to NOAA Atlas 14 data and a locally derived storm distribution. With many more years of data, better quality control, and more short duration measurements, much more confidence can be placed in the NOAA Atlas 14 precipitation-frequency estimates and storm distributions based on the estimates.

630.0406 Smoothing Precipitation Values from NOAA Atlas 14 Data

A. Background

(1) For a location with smooth data the incremental intensity for durations from 5 minutes through 24 hours plots as a line with either 1 or 2 straight-line segments on a log-log graph. Incremental intensity is defined in the Data Smoothing Technique section that follows.

(2) Using a 24-hour design storm distribution is standard practice in NRCS engineering design and is incorporated into the WinTR–20 (NRCS 2010a), WinTR–55 (NRCS 2009a), and EFH2 (NRCS 2014) computer programs. To best reflect the updated NOAA Atlas 14 (NWS 2005) partial duration precipitation frequency data, a site-specific distribution may be developed based on the updated NOAA Atlas 14 data. These data are downloaded from the NOAA Atlas 14 website as a comma-separated value (csv) file.

(3) As described in Merkel et al. (2006), investigations showed that developing regional storm distributions to replace the prior standard NRCS storm distributions (NRCS Types I, IA, II, and III) is feasible in States covered by NOAA Atlas 14.

(4) The primary assumption of NRCS storm distributions is that the maximum precipitation of all storm durations from 5 minutes to 24 hours occurs within the design storm, so that all precipitation intensities are represented in a single storm distribution. This allows the design storm distribution to be used for watersheds with times of concentration from 5 minutes to 24

hours. Otherwise, the engineer would have to develop or select a design storm distribution with a duration equal to the time of concentration that is unique to the watershed being analyzed.

(5) The basic data used to develop the rainfall distribution are the 5-minute through 24-hour precipitation for a particular return period, such as 25 years.

(6) Each duration in NOAA Atlas 14 was analyzed separately. For example, the maximum 60-minute value for each year was extracted and analyzed for precipitation-frequency. The specific techniques to derive mean, standard deviation, skew, and apply a probability distribution to the data are described in each volume of NOAA Atlas 14, respectively. Then the maximum 2-hour value for each year was extracted and analyzed for precipitation-frequency. This duration also had a mean, standard deviation, and skew. The maximum 3-, 6-, 12-, 24-hour, etc., durations were extracted from the data and analyzed separately; each with a calculated mean, standard deviation, and skew. No attempt was made to smooth these data across the series of durations for each return period. With all the limitations of the data being analyzed and the possibility of high or low values that could affect the skew, the curves for each duration could converge, diverge, or remain relatively parallel. If data are not smoothed, there is a possibility that the resulting storm distribution will not be smooth. This can potentially cause irregularities in a hydrograph developed from the storm distribution such as bumps, sharp rises and drops, and misplaced gradual increases or decreases in discharge.

B. Data Smoothing Technique

(1) Several mathematical techniques were investigated to determine a computationally efficient, accurate, practical, stable, and robust procedure. The relationship of rainfall intensity (inches per hour) and duration is smoothed since the generated hydrograph is primarily dependent on the relationship of precipitation intensity with duration.

(2) The relationship of intensity and duration is based on a factor defined as incremental intensity. Incremental intensity is defined as the difference in precipitation divided by the difference in duration. The incremental intensity for the 5-minute duration is equal to the 5-minute precipitation divided by 1/12 and has the units of inches per hour. The incremental intensity for the 10-minute duration is the 10-minute precipitation minus the 5-minute precipitation divided by 1/12 (the difference between 5 and 10 minutes in units of hours). Incremental intensity is calculated and smoothed for each return period independently.

(3) Plotting this relationship on a log-log scale, it may be a straight line, have slight curvature, or have several dips or waves. Examples of these non-smoothed plots follow in figures 4-48, 4-49, and 4-50.

Figure 4-48: Plot for Sun City, CA, Not Smooth Between 10 Minutes and 6 Hours

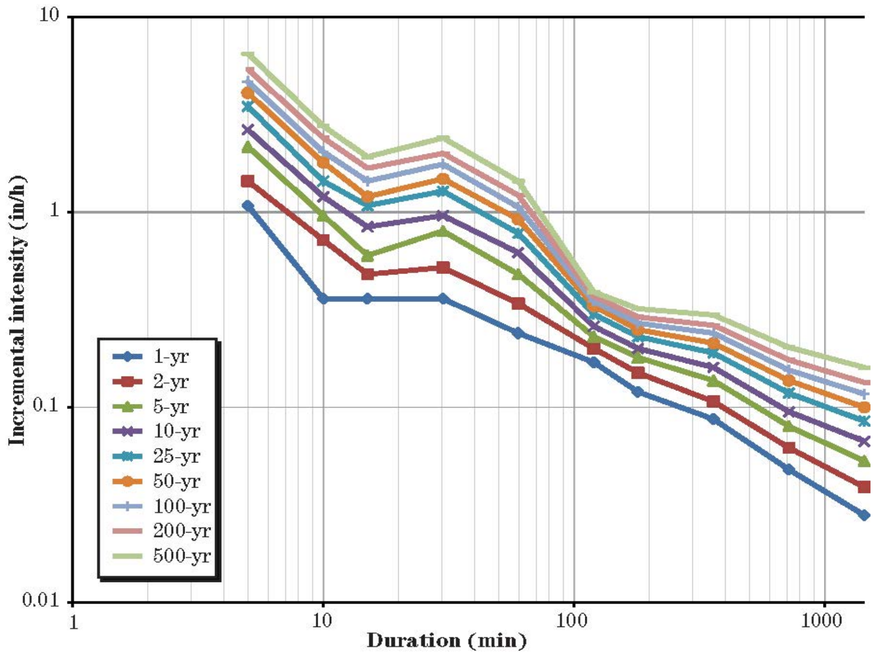


Figure 4-49: Curve with Irregularities at 15 Minutes and 3 Hours for Mercer County, NJ

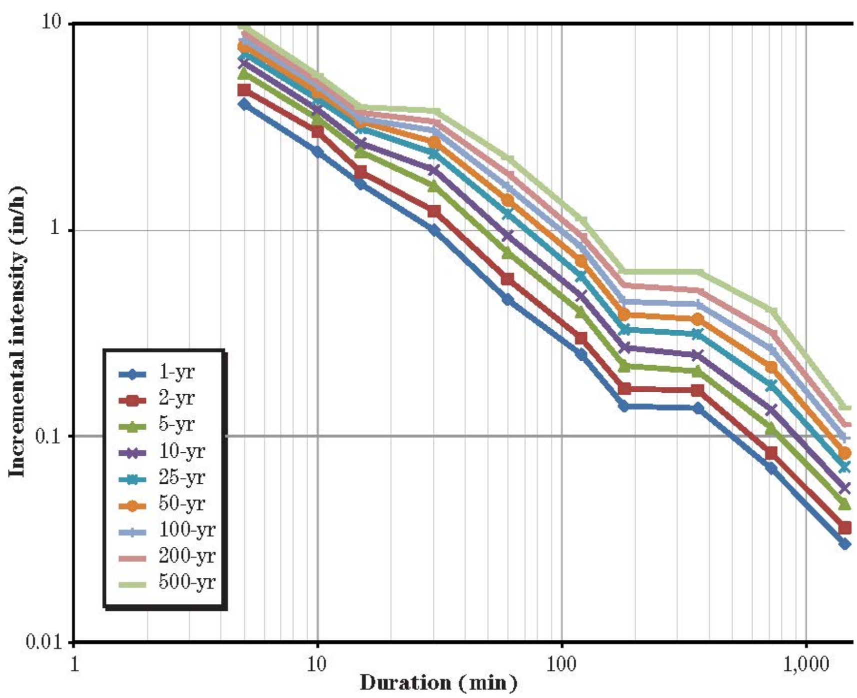
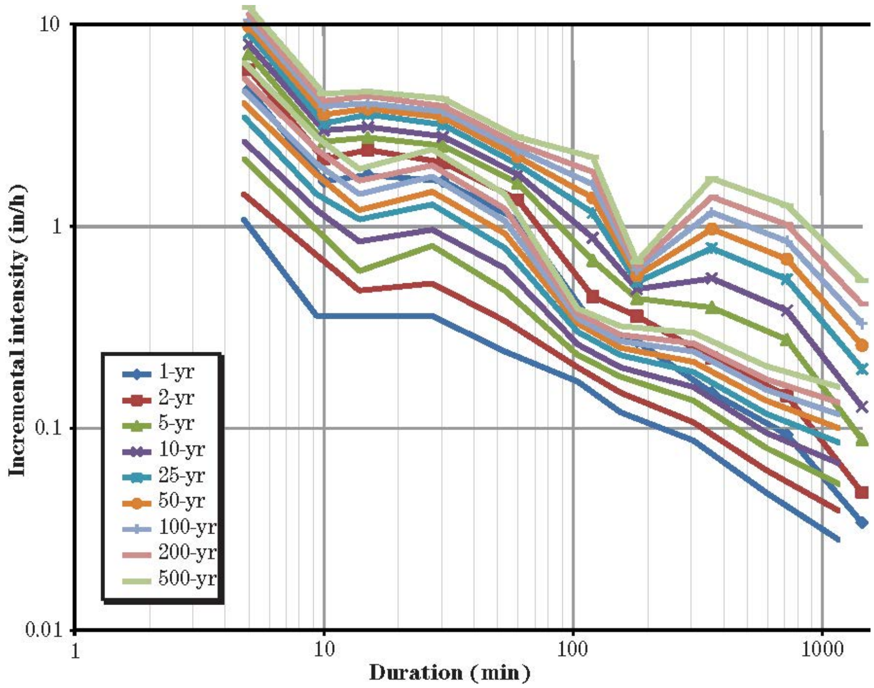


Figure 4-50: A Very Irregular Plot of Incremental Intensity for Bethlehem Upper Works, U.S. Virgin Islands



(4) Figures 5-51, 4-52, and 4-53 show three examples of the smoothing procedure. The smoothing procedure keeps the 60-minute and 24-hour precipitation unchanged from the original NOAA Atlas 14 partial duration values. The 5-, 10-, 15-, and 30-minute, and the 2-, 3-, 6-, and 12-hour values are open to adjustment. The smoothing procedure computes a straight line on the log-log plot that extends from 5-minute to 60-minute durations. The line is computed such that the squared difference between the smoothed 5-minute, 10-minute, 15-minute, and 30-minute incremental intensity values and the original values is minimized and the 60-minute precipitation is equal to the original value. A second straight-line segment is computed on the log-log plot that extends from the 60-minute value to the 24-hour (or 1440 minutes) value. This line is computed such that the incremental intensity for 60-minute duration is the same as calculated for the first line segment and the 60-minute and 24-hour precipitation values are unchanged. Calculating the adjusted values of precipitation involves a trial and error optimization procedure. The smoothing algorithm is available in the WinTR-20 system. Three examples follow, shown by figures 4-51, 4-52, and 4-53.

Figure 4-51: 25-Year Incremental Intensity Plot for Original and Smoothed Data for Mercer County, NJ

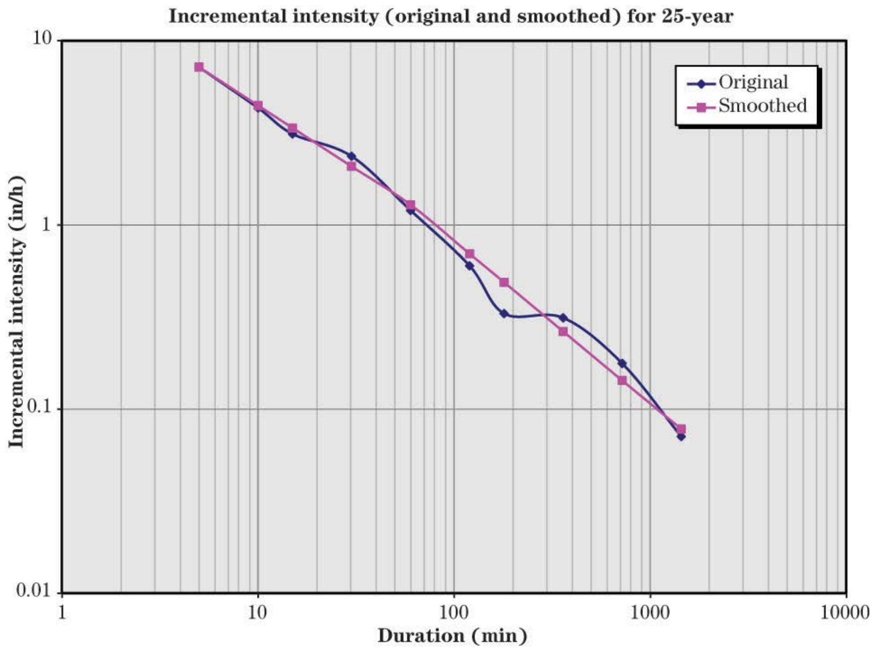


Figure 4-52: 25-Year Incremental Intensity Plot for Original and Smoothed Data for Phoenix, AZ

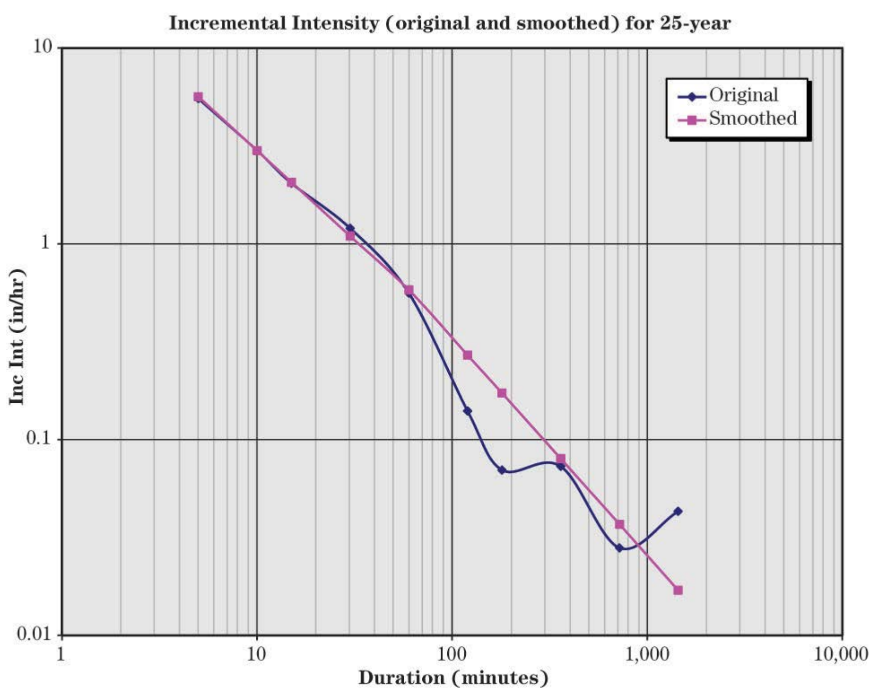
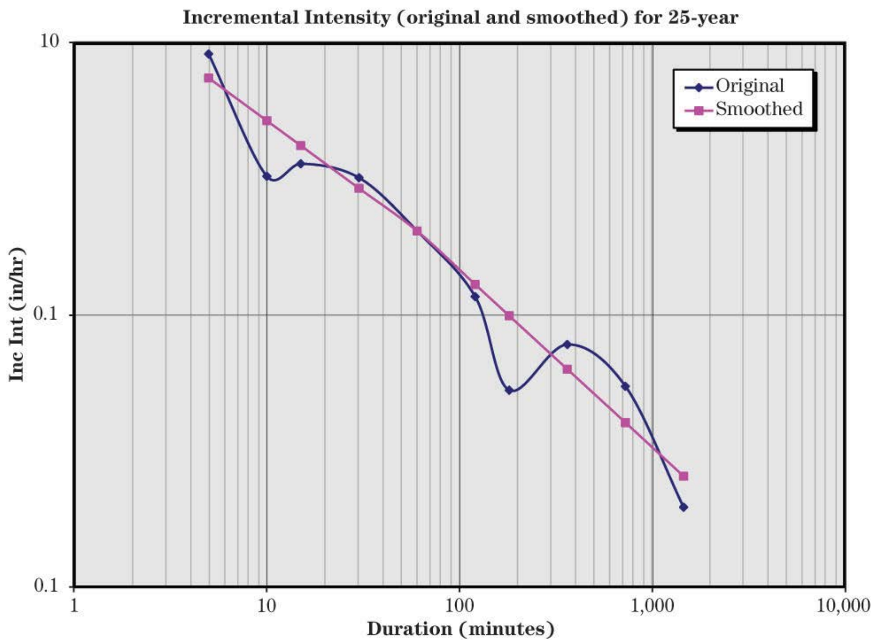


Figure 4-53: 25-Year Incremental Intensity Plot for Original and Smoothed Data for Bethlehem Upper Works, U.S. Virgin Islands



(5) The plot of 25-year storm hydrographs is based on original non-smoothed data (original) and smoothed data (smooth) for the three examples in figures 4-54, 4-55, and 4-56.

(6) The orange hydrograph (original) in figure 4-57 is based on the original data. The blue hydrograph (smooth) is based on the smoothed data. In this case, the peak discharge is practically the same and the hydrograph shape is very similar.

(7) In figure 4-55, the orange hydrograph (original) is based on the original data. The blue hydrograph (smooth) is based on the smoothed data. In this case, the two are somewhat different. Between about 18 and 24 hours, the hydrograph based on the original data increases slightly to 24 hours.

(8) In figure 4-56, the orange hydrograph (original) is based on the original data. The blue hydrograph (smooth) is based on the smoothed data. In this case, the two are visibly different. At about 11 hours, there is a slight dip in the hydrograph based on the original data. This has been eliminated in the hydrograph based on the smoothed NOAA Atlas 14 data.

(9) In WinTR–20, the user has the option to develop storm distributions based on the original precipitation-frequency data (NOAA Atlas 14 data) or smoothed data. A summary file is developed if the user chooses to smooth the data. This file contains the original precipitation data, the smoothed data, incremental intensity for both, and difference between the original data and the smoothed data. The name of the file is the same as the NOAA Atlas 14 .csv file except the extension is changed to .dff to represent the difference. Part of an example file is included in figure 4-57.

Figure 4-54: 25-Year Hydrograph Plots for Mercer County, NJ

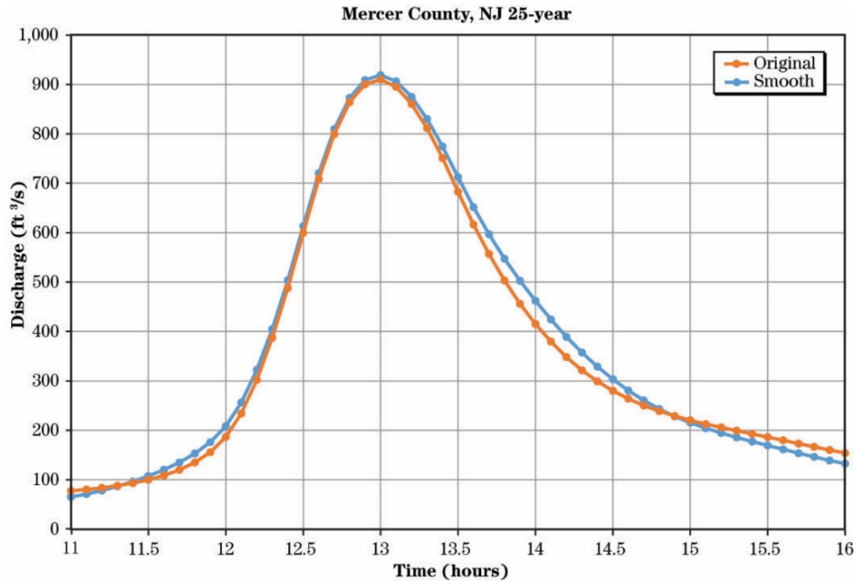


Figure 4-55: 25-Year Hydrograph Plots for Phoenix, AZ

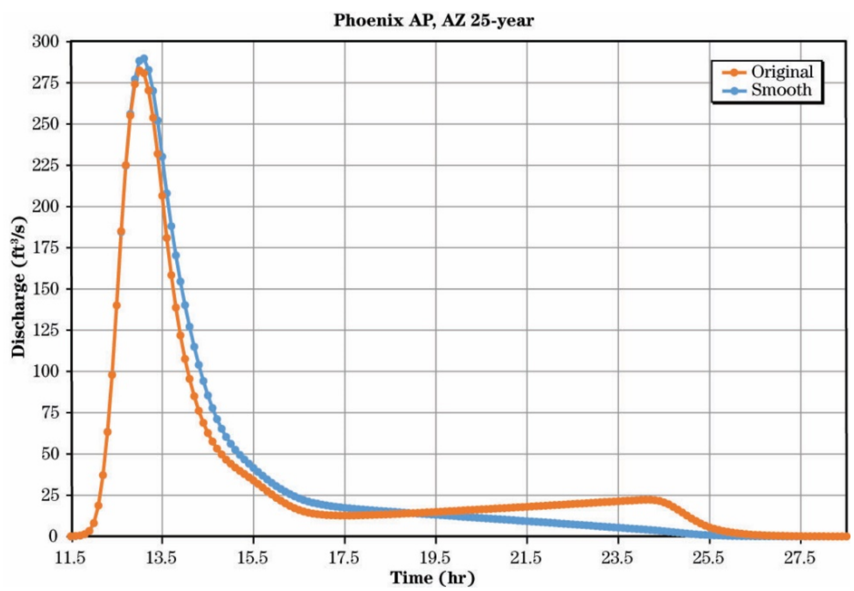


Figure 4-56: 25-Year Hydrograph Plots for Bethlehem Upper Works, U.S. Virgin Islands

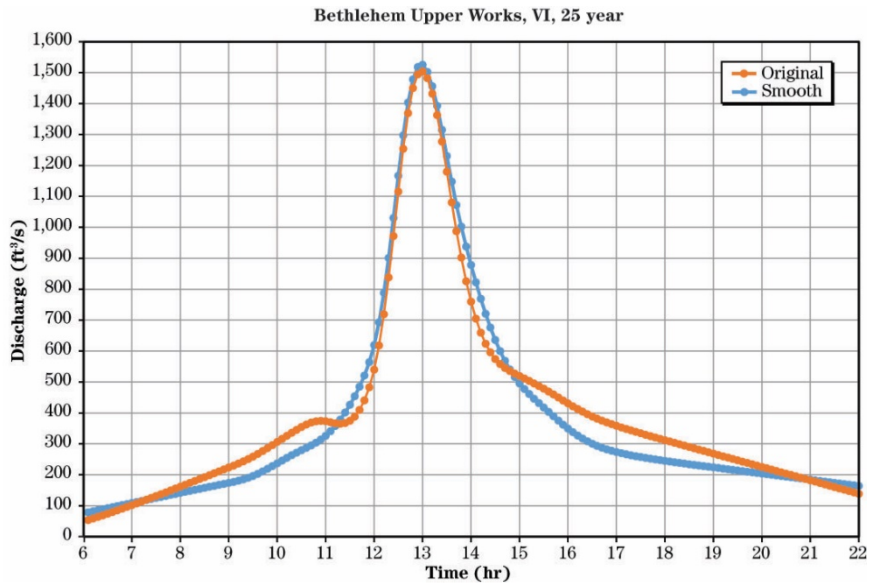


Figure 4-57: Table Showing Intensity Reversals for NOAA Atlas 14 data at Bethlehem Upper Works in the U.S. Virgin Islands

Data smoothing information 25 year										
Duration	**5 min**	**10 min**	**15 min**	**30 min**	**60 min**	**2 hr**	**3 hr**	**6 hr**	**12 hr**	**24 hr**
Precip	0.76	1.03	1.33	2.13	3.15	4.32	4.85	7.19	10.48	12.84
Inc_Int	9.120	3.240	3.600	3.200	2.040	1.170	0.530	0.780	0.548	0.197
Sm_Precip	0.62	1.05	1.40	2.13	3.15	4.45	5.44	7.34	9.76	12.84
Sm_Inc_Int	7.440	5.185	4.198	2.926	2.039	1.297	0.995	0.633	0.403	0.256
Precip_dif	– 0.140	0.022	0.072	0.003	0.000	0.127	0.592	0.152	– 0.722	0.000
Data smoothing information 50 year										
Duration	**5 min**	**10 min**	**15 min**	**30 min**	**60 min**	**2 hr**	**3 hr**	**6 hr**	**12 hr**	**24 hr**
Precip	0.82	1.12	1.44	2.31	3.42	4.81	5.38	8.30	12.44	15.54
Inc_Int	9.840	3.600	3.840	3.480	2.220	1.390	0.570	0.937	0.690	0.258
Sm_Precip	0.67	1.14	1.52	2.31	3.42	4.90	6.06	8.37	11.45	15.54
Sm_Inc_Int	8.040	5.616	4.553	3.180	2.221	1.475	1.161	0.0771	0.512	0.340
Precip_dif	– 0.150	0.018	0.077	0.002	0.000	0.085	0.677	0.071	– 0.994	0.000

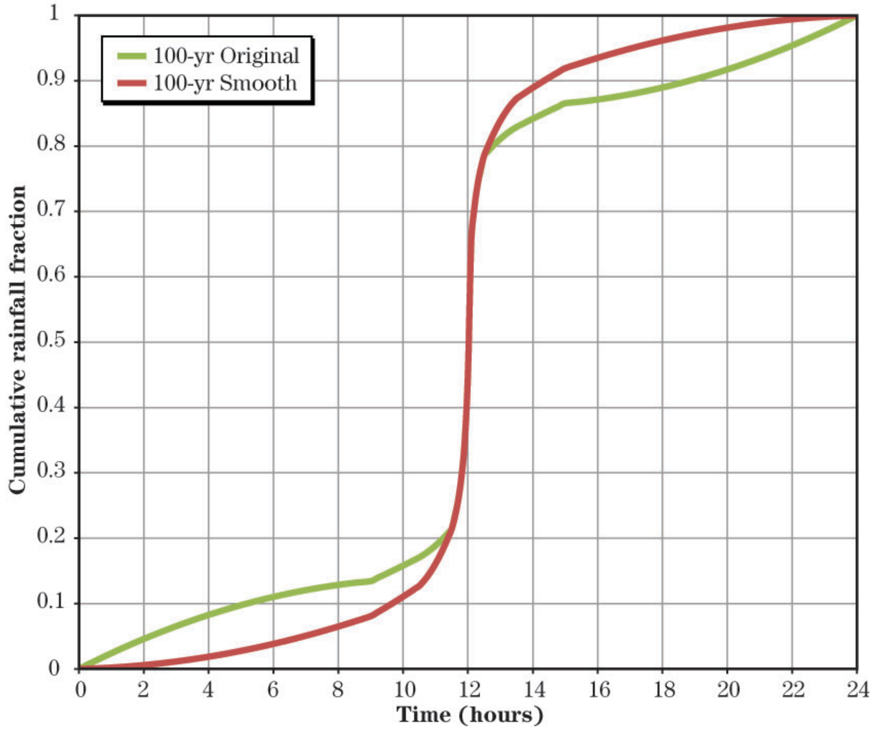
(10) In figure 4-57 for NOAA Atlas 14 data at Bethlehem Upper Works in the U.S. Virgin Islands, the incremental intensity increases from 10 to 15 minutes and from 3 to 6 hours. Since the incremental intensity should decrease from 5 minutes to 24 hours, this is an example where data smoothing is recommended.

(11) The first line in the table (Duration) lists the precipitation durations. The second line in the table (Precip) lists the original NOAA Atlas 14 precipitation data in inches. The third line (Inc_Int) is the incremental intensity for the original NOAA Atlas 14 precipitation data in units of inches per hour. The fourth line (Sm_Precip) is the smoothed precipitation values in inches (notice the 60-minute and 24-hour values are unchanged). The fifth line (Sm_Inc_Int) is the incremental intensity for the smoothed precipitation data in units of inches per hour. The sixth line (Precip_dif) is the difference between the NOAA Atlas 14 precipitation and the

smoothed values in inches. Figure 4-58 shows the rainfall distributions developed for the Phoenix Airport, AZ, based on the original and smoothed data.

(12) The rainfall distribution based on original data has several sharp breaks in slope at about 9, 11.5, 12.5, and 15 hours which will cause irregularities in the computed hydrograph.

Figure 4-58: Smooth and Original 100-Year Rainfall Distribution for Phoenix Airport



C. Examples of Smoothing NOAA Atlas 14 Data

(1) An example of impacts of smoothing data across durations is shown for St. George, UT. Part of the NOAA Atlas 14 partial duration data are shown in figure 4-59. Annual maximum precipitation for each duration is tabulated for the period of record. Maximum precipitation for each duration could happen on any day of the year and often, the maxima for various durations were not from the same storm event. For example, the maximum 5-minute precipitation and maximum 24-hour precipitation of the year may not be from the same storm event. When placing these durations into a maximized and centered design storm distribution, irregularities may occur.

(2) For the data in figure 4-59, an irregularity occurs between the 2-hour and 3-hour durations from the 10-year to 500-year return periods. Considering the 50-year return period, the additional precipitation between 2 hours and 3 hours is 0.05 inches (an intensity of only 0.05 inches per hour). The additional precipitation from 3 hours to 6 hours is 0.30 inches (an intensity of 0.10 inches per hour). The precipitation intensity for all other durations generally decreases as the duration increases. The precipitation-frequency for each duration is based on actual measurements. The major problem is that when setting up a maximized design storm distribution, when this type of intensity reversal occurs, the hydrograph generated by the storm distribution has an irregular shape, mostly evident in dips in the hydrograph before and

after the peak. The plot of a hydrograph using the St. George data for a 500-year return period is shown in figure 4-60.

(3) The hydrograph rises slightly between 13.0 and 15.0 hours. Using the zoom feature makes this more obvious; see figure 4-61.

(4) Figure 4-62 shows a hydrograph generated for a hypothetical watershed in the U.S. Virgin Islands using original data at Upper Bethlehem Works.

Figure 4-59: NOAA Atlas 14 Partial Duration Data for St. George, UT

	Average recurrence interval (years)								
Duration	**1**	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**
5-min:	**0.128** (0.111-0.148)	**0.163** (0.144-0.190)	**0.219** (0.190-0.251)	**0.266** (0.230-0.308)	**0.341** (0.291-0.392)	**0.405** (0.341-0.466)	**0.479** (0.394-0.555)	**0.561** (0.448-0.652)	**0.688** (0.526-0.816)
10-min:	**0.195** (0.169-0.225)	**2.49** (0.219-0.289)	**0.333** (0.289-0.382)	**0.405** (0.351-0.469)	**0.52** (0.443-0.596)	**0.617** (0.518-0.709)	**0.73** (0.599-0.844)	**0.855** (0.682-0.993)	**1.05** (0.805-1.24)
15-min:	**0.241** (0.209-0.279)	**0.309** (0.272-0.358)	**0.413** (0.359-0.474)	**0.502** (0.435-0.582)	**0.644** (0.550-0.739)	**0.765** (0.643-0.879)	**0.905** (0.743-0.844)	**1.06** (0.846-1.23)	**1.3** (0.993-1.54)
30-min:	**0.325** (0.282-0.376)	**0.416** (0.366-0.483)	**0.556** (0.483-0.638)	**0.676** (0.585-0.783)	**0.868** (0.740-0.995)	**1.03** (0.865-1.18)	**1.22** (1.00-1.41)	**1.43** (1.14-1.66)	**1.75** (1.34-2.08)
60-min:	**0.402** (0.349-0.465)	**0.514** (0.453-0.597)	**0.688** (0.598-0.790)	**0.837** (0.725-0.969)	**1.07** (0.916-1.23)	**1.27** (1.07-1.47)	**1.51** (1.24-1.75)	**1.77** (1.41-2.05)	**2.16** (1.66-2.57)
2-hr:	**0.489** (0.437-0.553)	**0.602** (0.542-0.687)	**0.779** (0.700-0.882)	**0.935** (0.834-1.06)	**1.18** (1.04-1.33)	**1.38** (1.19-1.55)	**1.6** (1.35-1.82)	**1.86** (1.53-2.13)	**2.24** (1.78-2.61)
3-hr:	**0.541** (0.488-0.605)	**0.67** (0.610-0.755)	**0.853** (0.774-0.955)	**1.01** (0.909-1.12)	**1.24** (1.11-1.39)	**1.43** (1.26-1.60)	**1.64** (1.41-1.85)	**1.87** (1.58-2.16)	**2.24** (1.83-2.64)
6-hr:	**0.669** (0.606-0.745)	**0.834** (0.763-0.932)	**1.05** (0.956-1.17)	**1.23** (1.11-1.38)	**1.5** (1.34-1.67)	**1.73** (1.51-1.93)	**1.96** (1.69-2.22)	**2.22** (1.88-2.53)	**2.6** (2.13-3.01)
12-hr:	**0.809** (0.736-0.893)	**1.01** (0.919-1.12)	**1.26** (1.14-1.39)	**1.48** (1.33-1.63)	**1.76** (1.58-1.95)	**1.98** (1.75-2.21)	**2.22** (1.93-2.49)	**2.46** (2.12-2.79)	**2.8** (2.35-3.20)
24-hour	**0.933** (0.87-0.994)	**1.16** (1.09-1.24)	**1.46** (1.37-1.55)	**1.69** (1.58-1.80)	**2.01** (1.87-2.14)	**2.26** (2.09-2.40)	**2.51** (2.31-2.67)	**2.76** (2.54-2.95)	**3.11** (2.82-3.33)

1/ Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS)

Figure 4-60: Hydrograph Based on St. George, UT, Original Rainfall Data

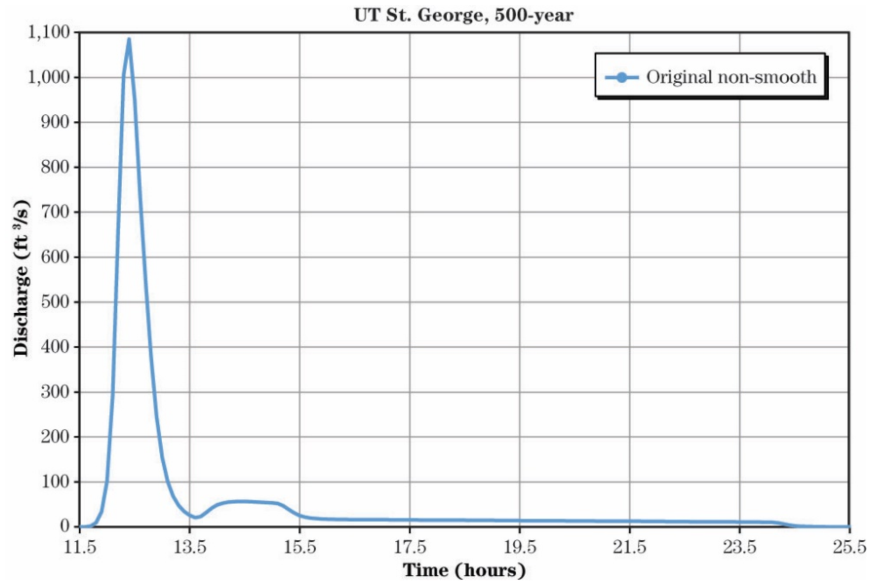


Figure 4-61: Detail of the Hydrograph Based on St. George, UT, Original Rainfall Data between 12.5 and 16.5 Hours Using the Zoom Feature

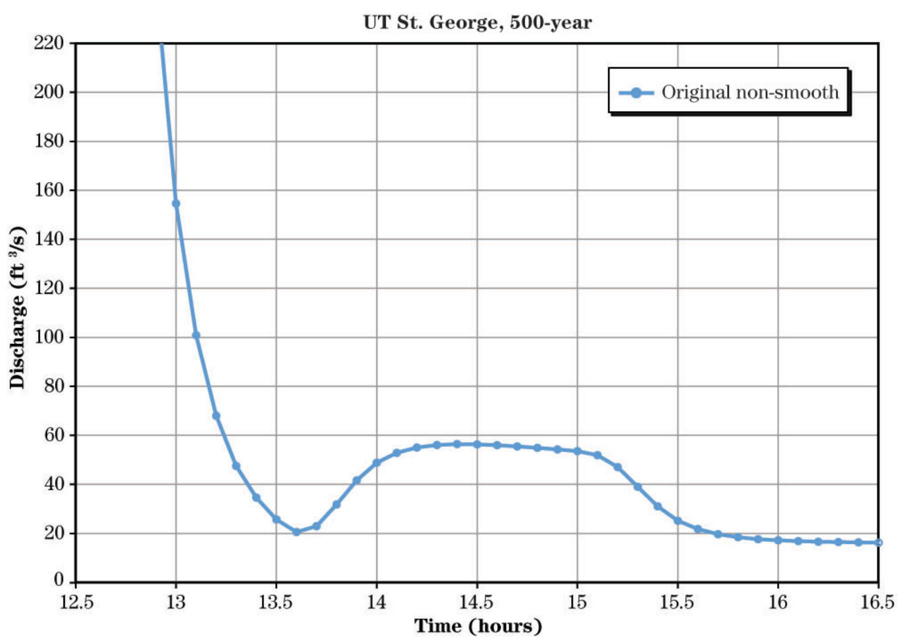
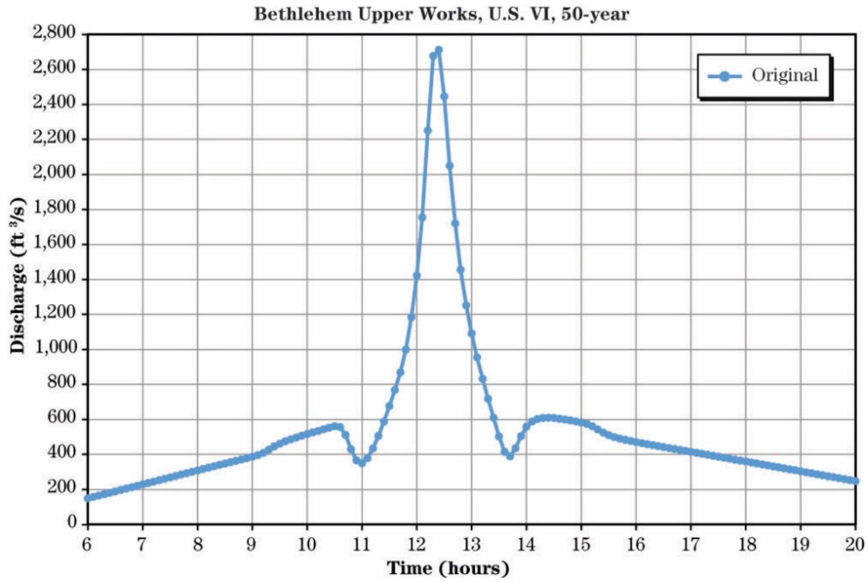


Figure 4-62: Hydrograph with Original Unsmoothed Data



D. Conclusion and Summary

(1) The technique for smoothing NOAA Atlas 14 precipitation data is described and demonstrated in this section. Impacts of smoothing data have been demonstrated for a hydrologic model of a watershed treated as a single unit (not divided into sub-watershed or subareas). If a hydrologic model were set up with a number of subareas, channel reaches, reservoirs, and diversions, the shape of hydrographs is important because they are added, routed, split, etc. If data are not smoothed, the irregularly shaped hydrographs may cause unexpected results.

(2) In testing where these irregularities occur, the States covered by NOAA Atlas 14 volumes 1 – Semi-arid Southwest (NWS 2006a), 3 – Puerto Rico and US Virgin Islands (NWS 2006c), 4 – Hawaiian Islands (NWS 20011a), 5 – Pacific Islands (NWS 2011b), 6 – California (NWS 2011c), and 7 – Alaska (NWS 2012) show the most need for the data to be smoothed in order to produce relatively smooth hydrographs. States in the Ohio River Basin, Midwest, and Southeast – NOAA Atlas volumes 2 (NWS 2006b), 8 (NWS 2013a), and 9 (NWS 2013b) – show a lesser degree of this irregularity of precipitation intensity.

(3) As a general guideline, smoothing the data when applying the WinTR-20 hydrologic model is recommended. Regional rainfall distributions developed for California, Nevada, Midwest and southeast States, Ohio Valley and neighboring States, and others are based on smooth NOAA Atlas 14 data.

630.0407 Development of 24-Hour Rainfall Distribution From 5-Minute Through 24-Hour Rainfall Values

A. Introduction

This section covers the procedure to develop a 24-hour rainfall distribution from a set of rainfall data values for 5-minute through 24-hour durations. This procedure may be repeated for each return period from 1 to 500 years. The following procedure to operate with partial duration precipitation values is incorporated into the NRCS hydrologic model WinTR–20 (NRCS 2010a). The data used in this section were downloaded for Columbus, OH, WSO Airport in the area covered by NOAA Atlas 14, volume 2 (NWS 2006b).

B. Procedure

Input to this procedure consists of precipitation values for 5-, 10-, 15-, 30-, and 60-minute and 2-, 3-, 6-, 12-, and 24-hour durations for a single recurrence interval such as the 25-year-average recurrence interval. The procedure to develop the 24-hour rainfall distribution applies to both original data and smoothed data (see 630.0406 for data smoothing technique).

(i) Step 1.—Calculate ratios of shorter duration to 24-hour precipitation. The 25-year return period original (non-smoothed) values are used in this example. Figure 4-63 includes duration, precipitation values, and calculated ratios to the 24-hour value. For example, the 60-minute value is 2.25 inches, and the 24-hour value is 4.44 inches. Therefore, the ratio is 0.5068.

(ii) Step 2.—Calculate a preliminary rainfall distribution based on the ratios from figure 4-63. Figure 4-64 shows the time in clock hours, time in decimal hours, and preliminary cumulative rainfall ratios.

- Since the preliminary rainfall distribution is symmetrical about 12 hours, figure 4-63 shows the 12-/24-hour ratio to be 0.8784 for this example. Thus, 87.84 percent of the rain will fall between 6 and 18 hours. Since the rainfall distribution is symmetrical about 12 hours, half of this rain will fall before 12 hours and half will fall after 12 hours. The cumulative rain ratio at 6 hours of the preliminary distribution is 0.5 – (12-/24-hr ratio)/2 or in equation form—

  $0.5 - (0.8784 / 2) = 0.0608$
- The 6-/24-hour ratio is placed from 9 hours to 15 hours of the 24-hour rainfall distribution. The cumulative rain ratio at 9 hours of the preliminary distribution is 0.5 – (6-/24-hr ratio)/2 or in equation form—

  $0.5 - (0.7568 / 2) = 0.1216$
- The 10-minute/24-hour ratio is used to calculate the cumulative rain ratio at 11.9167 hours. The cumulative rain ratio at 11.9167 hours of the preliminary distribution is 0.5 – (10-min/24-hr ratio)/2 or in equation form—

  $0.5 - (0.2252 / 2) = 0.3874$
- The 5-minute/24-hour ratio is used in step 8.
- Figure 4-67 becomes the basis for interpolating a rainfall distribution for 24 hours at a time increment of 0.1 hour.

(iii) Step 3.—Determine cumulative rain ratios for times from 0.0 to 9.0 hours (figure 4-65).

$CRR(t) = a(t^2) + bt$ (eq. 4–1)

Where—

CRR(t) = cumulative rain ratio at time t hours

$a = (2/3\ CRR(9) - CRR(6))/18$

$b = (CRR(6) - 36a)/6$

(iv) Step 4.—Determine cumulative rain ratios for times from 9.0 to 10.5 hours (fig. 4-66). An equation is developed such that the cumulative rainfall ratio gradually and constantly increases between 9.0 and 10.5 hours yet still matches the ratios at 9.0 and 10.5 hours in figure 4-64.

$CRR(t) = a_2(t^2) + b_2 t$ (eq. 4–2)

Where—

CRR(t) = cumulative rain ratio at time t hours

$a_2 = (9/10.5\ CRR(10.5) - CRR(9)) / 13.5$

$b_2 = (CRR(9) - 81a_2)/9$

(v) Step 5.—Determine cumulative rain ratios for times from 10.5 to 11.5 hours (figure 4-67). An equation is developed such that the cumulative rainfall ratio gradually and constantly increases between 10.5 and 11.5 hours yet still matches the ratios at 10.5, 11.0, and 11.5 hours in figure 4-64.

$CRR(t) = a_3 (t^2) + b_3 t + c_3$ (eq. 4–3)

Where—

CRR(t) = cumulative rain ratio at time t hours

$a_3 = 2 (CRR(11.5) – 2 CRR(11) + CRR(10.5))$

$b_3 = CRR (11.5) – CRR(10.5) – 22a_3$

$c_3 = 11 – 121a_3 – 11b_3$

(vi) Step 6.—Determine cumulative rain ratios for times from 11.6 to 11.9 hours (figure 4-68).

CRR(11.6) = CRR(11.5) + Factor(11.6)(CRR(11.75) − CRR(11.5))

Where—

Factor(11.6)=– 0.867 Intensity(11.5)+0.4337

Intensity(11.5)=(CRR(11.5) – CRR(11.4))/0.1

The value of Factor(11.6) has a maximum value of 0.399. If the value of Factor (11.6) is greater than 0.399, it is changed to 0.399.

Intensity(11.5) = (0.2466 – 0.2349) / 0.1 = 0.117

Factor(11.6) = (– 0.867 × 0.117) + 0.4337 = 0.3322

CRR(11.6) = 0.2466 + 0.3322 × (0.3041 – 0.2466) =0.2657.

CRR(11.7) = CRR(11.5) + Factor(11.7)(CRR(11.75) − CRR(11.5))

Where—

Factor(11.7) = – 0.4917 (Intensity(11.5)) + 0.8182

The value of Factor(11.7) has a maximum value of 0.799.

Factor(11.7) = (–0.4917 × 0.117)+0.8182 = 0.7607

CRR(11.7) = 0.2466+0.7067×(0.3041–0.2466)=0.2903

CRR(11.8)=CRR(11.75)+(11.8–11.75)/(11.875–11.75)(CRR(11.875)–CRR(11.75))

CRR(11.8)=0.3041+0.4(0.3615–0.3041)=0.3270

CRR(11.9)=CRR(11.875)+(11.9–11.875)/(11.9167–11.875)(CRR(11.9167)–CRR(11.875))

CRR(11.9)=0.3615+0.6(0.3874–0.3615)=0.3770

(vii) Step 7.—Determine cumulative rain ratios for times from 12.1 to 24 hours (fig. 4-69). Since the rainfall distribution is symmetrical, the cumulative rain ratios from 12.1 to 24 hours are based on the cumulative rain ratios from 0.0 to 11.9 hours. The cumulative rain ratio at 12.1 hours is 1.0 minus the cumulative rain ratio at 11.9 hours. The cumulative rain ratio at 12.2 hours is 1.0 minus the cumulative rain ratio at 11.8 hours. This continues all the way to 24 hours (where the 24-hour cumulative rain ratio is 1.0 – 0.0 or 1.0).

Figure 4–63: Duration, Precipitation, and Ratio Values, Columbus, OH, WSO Airport for the 25-Year Return Period

Duration	**5 min**	**10 min**	**15 min**	**30 min**	**60 min**	**2 hr**	**3 hr**	**6 hr**	**12 hr**	**24 hr**
Precipitation (inches)	0.65	1.00	1.23	1.74	2.25	2.67	2.84	3.36	3.90	4.44
Ratio to 24-hr	0.1464	0.2252	0.2770	0.3919	0.5068	0.6014	0.6396	0.7568	0.8784	1.00

Figure 4-64: Preliminary Cumulative Rain Ratio Values

Clock time	Time (hours)	Preliminary cumulative rain ratio
0:00 AM	0.0	0.0
6:00	6.0	0.0608
9:00	9.0	0.1216
10:30	10.5	0.1802
11:00	11.0	0.1993
11:30	11.5	0.2466
11:45	11.75	0.3041
11:52:30	11.875	0.3615
11:55	11.9167	0.3874
12:05 PM	12.0833	0.6126
12:07:30	12.125	0.6385
12:15	12.25	0.6959
12:30	12.5	0.7534
1:00	13.0	0.8007
1:30	13.5	0.8198
3:00	15.0	0.8784
6:00	18.0	0.9392
12:00 AM	24.0	1.0

Figure 4-65: Cumulative Rain Ratios from 0.0 to 9.0 Hours

Time (hours)	Cumulative rain ratio	Time (hours)	Cumulative rain ratio	Time (hours)	Cumulative rain ratio	Time (hours)	Cumulative rain ratio
0.0	0.0000	2.3	0.0137	4.6	0.0394	6.9	0.0769
0.1	0.0003	2.4	0.0146	4.7	0.0408	7.0	0.0788
0.2	0.0007	2.5	0.0155	4.8	0.0422	7.1	0.0808
0.3	0.0011	2.6	0.0164	4.9	0.0436	7.2	0.0827
0.4	0.0015	2.7	0.0173	5.0	0.0450	7.3	0.0847
0.5	0.0020	2.8	0.0183	5.1	0.0465	7.4	0.0867
0.6	0.0024	2.9	0.0193	5.2	0.0480	7.5	0.0887
0.7	0.0029	3.0	0.0203	5.3	0.0495	7.6	0.0907
0.8	0.0034	3.1	0.0213	5.4	0.0511	7.7	0.0928
0.9	0.0040	3.2	0.0223	5.5	0.0526	7.8	0.0949
1.0	0.0045	3.3	0.0234	5.6	0.0542	7.9	0.0970
1.1	0.0051	3.4	0.0245	5.7	0.0558	8.0	0.0991
1.2	0.0057	3.5	0.0256	5.8	0.0575	8.1	0.1013
1.3	0.0063	3.6	0.0268	5.9	0.0591	8.1	0.1013
1.4	0.0069	3.7	0.0279	6.0	0.0608	8.2	0.1034
1.5	0.0076	3.8	0.0291	6.1	0.0625	8.3	0.1056
1.6	0.0083	3.9	0.0303	6.2	0.0642	8.4	0.1078
1.7	0.0090	4.0	0.0315	6.3	0.0660	8.5	0.1101
1.8	0.0097	4.1	0.0328	6.4	0.0677	8.6	0.1123
1.9	0.0105	4.2	0.0341	6.5	0.0695	8.7	0.1146
2.0	0.0113	4.3	0.0353	6.6	0.0714	8.8	0.1169
2.1	0.0121	4.4	0.0367	6.7	0.0732	8.9	0.1193
2.2	0.0129	4.5	0.0380	6.8	0.0750	9.0	0.1216

Figure 4–66: Cumulative Rain Ratios from 9.0 to 10.5 Hours

Time (hours)	Cumulative rain ratio
9.0	0.1216
9.1	0.1252
9.2	0.1288
9.3	0.1325
9.4	0.1362
9.5	0.1399
9.6	0.1437
9.7	0.1476
9.8	0.1515
9.9	0.1554
10.0	0.1594
10.1	0.1635
10.2	0.1676
10.3	0.1717
10.4	0.1759
10.5	0.1802

Figure 4-67: Cumulative Rain Ratios from 10.5 to 11.5 Hours

Time (hours)	Cumulative rain ratio
10.5	0.1802
10.6	0.1818
10.7	0.1845
10.8	0.1883
10.9	0.1932
11.0	0.1993
11.1	0.2065
11.2	0.2149
11.3	0.2243
11.4	0.2349
11.5	0.2466

Figure 4-68: Cumulative Rain Ratios from 11.6 to 11.9 Hours

Time (hours)	Cumulative Rain Ratio
11.6	0.2657
11.7	0.2903
11.8	0.3270
11.9	0.3770

Figure 4-69: Cumulative Rain Ratios from 12.1 to 24.0 Hours

Time (hours)	Cumulative rain ratio	Time (hours)	Cumulative rain ratio	Time (hours)	Cumulative rain ratio
12.1	0.6230	16.1	0.9030	20.1	0.9697
12.2	0.6730	16.2	0.9051	20.2	0.9709
12.3	0.7097	16.3	0.9072	20.3	0.9721
12.4	0.7343	16.4	0.9093	20.4	0.9732
12.5	0.7534	16.5	0.9113	20.5	0.9744
12.6	0.7651	16.6	0.9133	20.6	0.9755
12.7	0.7757	16.7	0.9153	20.7	0.9766
12.8	0.7851	16.8	0.9173	20.8	0.9777
12.9	0.7935	16.9	0.9192	20.9	0.9787
13.0	0.8007	17.0	0.9212	21.0	0.9797
13.1	0.8068	17.1	0.9231	21.1	0.9807
13.2	0.8117	17.2	0.9250	21.2	0.9817
13.3	0.8155	17.3	0.9268	21.3	0.9827
13.4	0.8182	17.4	0.9286	21.4	0.9836
13.5	0.8198	17.5	0.9305	21.5	0.9845
13.6	0.8241	17.6	0.9323	21.6	0.9854
13.7	0.8283	17.7	0.9340	21.7	0.9863
13.8	0.8324	17.8	0.9358	21.8	0.9871
13.9	0.8365	17.9	0.9375	21.9	0.9879
14.0	0.8406	18.0	0.9392	22.0	0.9887
14.1	0.8446	18.1	0.9409	22.1	0.9895
14.2	0.8485	18.2	0.9425	22.2	0.9903
14.3	0.8524	18.3	0.9442	22.3	0.9910
14.4	0.8563	18.4	0.9458	22.4	0.9917
14.5	0.8601	18.5	0.9474	22.5	0.9924
14.6	0.8638	18.6	0.9489	22.6	0.9931
14.7	0.8675	18.7	0.9505	22.7	0.9937
14.8	0.8712	18.8	0.9520	22.8	0.9943
14.9	0.8748	18.9	0.9535	22.9	0.9949
15.0	0.8784	19.0	0.9550	23.0	0.9955
15.1	0.8807	19.1	0.9564	23.1	0.9960
15.2	0.8831	19.2	0.9578	23.2	0.9966
15.3	0.8854	19.3	0.9592	23.3	0.9971
15.4	0.8877	19.4	0.9606	23.4	0.9976
15.5	0.8899	19.5	0.9620	23.5	0.9980
15.6	0.8922	19.6	0.9633	23.6	0.9985
15.7	0.8944	19.7	0.9647	23.7	0.9989
15.8	0.8966	19.8	0.9659	23.8	0.9993
15.9	0.8988	19.9	0.9672	23.9	0.9997
16.0	0.9009	20.0	0.9685	24.0	1.0000

(viii) Step 8.—Determine cumulative rain ratio for time 12.0 hours.

- Since the rainfall distribution is developed at a time increment of 0.1 hour (6 min.), the 5-minute/24-hour and 10-minute/24-hour ratios are used to calculate the maximum 6-minute rainfall ratio.

  6-min / 24-hr ratio = 5-min / 24-hr ratio + 0.2 (10-min /24-hr ratio – 5-min /24-hr ratio)

  6-min / 24-hr ratio = 0.1464 + 0.2 (0.2252 – 0.1464) = 0.16216
- The 6-minute /24-hour rainfall ratio is subtracted from the cumulative rain ratio at 12.1 hours in order to define a cumulative rain ratio at 12.0 hours. By making this

adjustment, the maximum 5-minute rainfall ratio is represented in the final rainfall distribution.

Ratio(12.0) = Ratio(12.1) - 6-minute/24-hour ratio

Ratio (12.0) = 0.62297 – 0.16216 = 0.46081

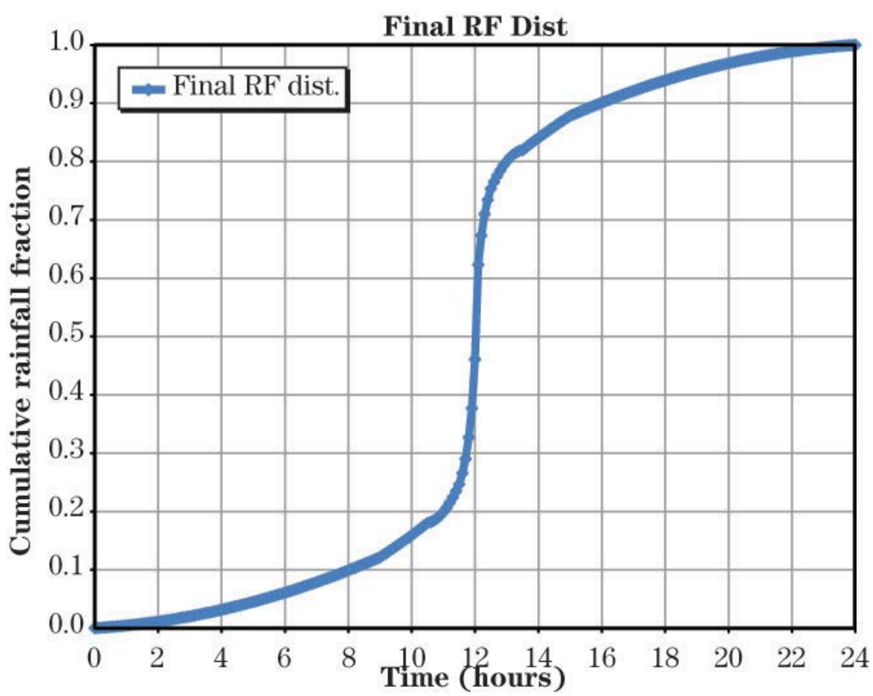
- The rainfall distribution algorithm is programmed in WinTR–20. In WinTR–20, this procedure is completed for all return periods from 1 to 500 years. Each return period will have a unique rainfall distribution.

C. Discussion

(1) In step 3, curves are used to interpolate the cumulative rain ratio at the 0.1-hour time steps. It seems logical to interpolate the ratios at these time steps linearly from the preliminary rainfall distribution in figure 4-64. If that is done, there will be irregularities in the hydrograph developed from the rainfall distribution. These irregularities include sharp changes in discharge at rainfall distribution break points (such as 6 and 9 hours) and gradual increases in discharge on the falling tail of the hydrograph. For these reasons, equations are developed such that the cumulative rainfall ratio gradually and constantly increases between 0 and 11.9 hours yet still matches the ratios in figure 4-64.

(2) The rainfall distribution developed in steps 1 through 8 is plotted in figure 4-70.

Figure 4-70: Rainfall Distribution Developed in Example in 630.0407



D. Summary

The NRCS procedure for developing a storm distribution based on precipitation values at durations from 5 minutes to 24 hours is documented in this section. The procedure is implemented in the WinTR–20 computer program and is also available in a spreadsheet available from the WNTSC National Water Quality and Quantity Team website http://go.usa.gov/rXYw (NRCS 2011) under "Technical Information." By documenting the assumptions and procedure, the procedure becomes more transparent and understandable. In future years, when more research is available on storm structure, hydraulic engineers will be able to make improvements to the procedure.

630.0408 Example of Determining a Design Rainfall Distribution for a Region Based on GIS Data

A. Introduction

(1) This section describes development of four regional standardized rainfall distributions for the Ohio Valley and neighboring States in the NOAA Atlas 14 Volume 2 (NWS, 2006b) area. Other NRCS technical literature, including software user guides, training materials, and State supplements, describe use of these rainfall distributions.

(2) Use of a regional rainfall distribution may produce different peak discharges than if the site-specific rainfall distribution is used. This is because the ratios of shorter duration, such as 60 minutes to 24-hour rainfall, vary across the region. Also, if the regional rainfall distribution is based on a single storm, such as the 25-year, a site-specific 100-year rainfall distribution may be different and produce different peak discharges. For this reason, the regional rainfall distributions were tested against site-specific distributions and differences in results were evaluated.

(3) This section is written for an intermediate or advanced GIS user. A person with little GIS experience could find this material difficult to understand. If this is the case, ask a more experienced GIS user for an explanation. Even though the recommended method for developing a rainfall distribution is on a site-by-site basis with a unique distribution for each return period, sometimes a rainfall distribution covering a geographic area is desirable. For small-scale NRCS hydrologic projects, the NRCS EFH2 (NRCS 2014) – based on Title 210, National Engineering Handbook, Part 650, Chapter 2, "Engineering Field Handbook" (EFH) (NRCS 1993) – and WinTR–55 (NRCS 2009a) computer programs are used. These software programs are not capable of developing site-specific rainfall distributions and must rely on predeveloped rainfall distributions. For this reason, regional rainfall distributions were developed. In some localities, maps of ratios of shorter duration to the 24-hour rainfall based on GIS layers from NOAA Atlas 14 show high and low bull's-eyes that do not appear logical considering local meteorological conditions. These may be influenced by the results of the statistical analysis of a single rain gage. By developing a regional rainfall distribution, these high and low ratio areas are smoothed out and result in a single more representative rainfall distribution.

B. Procedure

(1) Step 1.—Prepare GIS data layers to include a base map or shapefile of State and county boundaries and rainfall data at durations from 5 minutes to 24 hours for the return periods of interest. The NOAA Atlas 14 data layers may be prepared using instructions available from the WNTSC National Water Quality and Quantity Team website at http://go.usa.gov/KoZ under WinTR–20.

(2) Step 2.—Develop ratios of the 5-minute to 24- hour, 10-minute to 24-hour, up to the 12-hour to 24-hour duration for return periods of interest using GIS grid layers for the project area. If using Environmental Systems Research Institute (ESRI) GIS software, use the "Spatial Analyst Math" commands.

(3) Step 3.—Decide which return period is the most important on which to base the regional rainfall distribution. The primary consideration in making this decision is what the rainfall distribution will be used for. In the case of NRCS regional rainfall distributions, they will be used primarily to design projects based on the 25-year return period 24-hour rainfall. It will also be used to a lesser degree for design of projects with 10- and 50-year, 24-hour rainfalls. An analysis of ratios of shorter duration to the 24-hour rainfall will show how different the rainfall distributions could be between selected return periods. For example, in many locations, the ratios for all return periods are similar which would result in very similar

rainfall distributions. However, if the ratios are significantly different, then different rainfall distributions would be developed (such as the case in Wilmington, NC, NEH630.0403B "Precipitation – Frequency Data Ratio Analyses").

(4) Step 4.—Depending on the purpose of the study, either decide on the region for which to develop a single rainfall distribution or decide how many rainfall distributions are desired within a certain geographic area. For example, an average rainfall distribution is desired for a single State. Another example could be to develop a number of rainfall distribution regions for a given State or group of States. Depending on this decision, different procedures are used from this point.

(i) Step 4A.—If an average rainfall distribution is desired for a single State, use the ESRI Spatial Analyst commands to determine the zonal statistics for areas within the State boundary. The Zonal Statistics command will produce the mean, maximum, minimum, and range of the ratios for each duration within the selected return period (such as 25 years). Once these means are computed, compile the mean ratios for 5 minutes to 12 hours and build a rainfall distribution based on principles described in this chapter. These principles may include smoothing the ratios before building the rainfall distribution.

(ii) Step 4B.—For the second project type, dividing a geographic area into a number of rainfall distribution regions, first decide on the most important duration ratio on which to base the boundaries of the rainfall regions, such as the 60-minute to 24-hour ratio. Analyze the selected ratio map and determine the maximum and minimum ratios. Then divide the range of ratios into an appropriate number of regions. For example, if the range of 60-minute to 24-hour ratio is from 0.3 to 0.5, a logical procedure would be to break the area up into four rainfall distribution regions based on ratios from 0.3 to 0.35, 0.35 to 0.4, 0.4, to 0.45, and 0.45 to 0.5. To do this analysis using ESRI tools, use the "Spatial Analyst Reclassify" command and set the limits of each class to the desired intervals such as region 1 with ratios less than 0.35, region 2 with ratios between 0.35 and 0.4, region 3 with ratios between 0.4 and 0.45, and region 4 with ratios greater than 0.45. Convert this reclassified GIS layer into a polygon shapefile where the boundaries follow the four rainfall distribution regions. If the boundaries are satisfactory, proceed to the next step. If the boundaries are not reasonable, reset the number of regions, the ratio limits for each region, or both and reclassify again.

(5) This analysis will define the regional boundaries only. To build a rainfall distribution for each of these regions, ratios of 5 minutes to 24 hours up to the 12- to 24-hour ratio are required. If using ESRI GIS software, use the "Spatial Analyst Zonal Statistics as Table" command. Use this command for each duration ratio and the regional distribution map (shapefile) to determine the mean ratio for each duration within each region. Once the ratios for each duration have been computed, the ratios may be smoothed and a rainfall distribution developed based on principles outlined in this chapter.

C. Example Application

(1) The second project type is to divide a geographic area into a number of rainfall distribution regions. This approach was used to develop four rainfall distribution regions for the States covered by NOAA Atlas 14 Volume 2, the Ohio Valley, and neighboring States.

(2) The intended purpose of the rainfall distributions was to use them in the EFH2 computer program. The 25-year frequency was used as the basis for the rainfall distribution because many conservation practices are designed for the 25-year return period storm.

(3) The 25-year rainfall distribution is midway between the 1- and 100-year rainfall distributions. The 10- and 50-year rainfall distributions are generally close enough to the 25-year rainfall distribution that minor differences in the rainfall distribution and peak discharge will result.

(4) The GIS data for the 5-minute to 24-hour durations were downloaded from the NOAA Atlas 14 website and prepared using ESRI software. A base map of States and counties was prepared in the same GIS map projection. Ratios of 5 minutes to 24 hours, 10 minutes to 24 hours, etc. were determined using ESRI "Spatial Analyst" commands.
(5) The 60-minute to 24-hour ratio was used to determine the boundaries of the rainfall distribution regions. This was selected because the 5- through 30-minute rainfall values are determined based on a percentage of the 60-minute rainfall. Therefore, the boundaries developed using the 60-minute ratio should be generally consistent with the boundaries developed by using any duration between 5 and 30 minutes. Many watersheds where EFH chapter 2 is applied have a time of concentration less than 60 minutes.
(6) The 60-minute to 24-hour ratio ranged from 0.28 to 0.58 and was reclassified into four regions with 60-minute/24-hour ratios of less than 0.38, 0.38 to 0.43, 0.43 to 0.48, and greater than 0.48. This analysis produced the map in figure 4-71. The number of rainfall distribution regions and ratio limits for each one is a subjective decision that includes consideration of several factors. Perhaps the major factor is the difference in peak discharge when changing from one distribution region to another. Once a set of distribution regions and rainfall distributions are organized, tests can be run to determine this difference. For example, if the peak discharge for region A is 100 cubic feet per second, region B is 90 cubic feet per second, region C is 80 cubic feet per second, and region D is 70 cubic feet per second, the potential error is plus or minus 5 cubic feet per second. After converting this to a percentage difference, judge whether this is a reasonable percentage tolerance for hydrologic design. A second consideration is the relative size of rainfall distribution regions. It may not be reasonable to have one distribution region much larger or smaller than another. A third consideration is the absolute limit of the ratios. For example, if the ratio range for the most intense and least intense rainfall distribution is large, then the potential error in discharge may exceed the desired tolerance.
(7) Region A has 60-minute to 24-hour ratios greater than 0.48, region B has ratios between 0.43 and 0.48, region C has ratios between 0.38 and 0.43, and region D has ratios less than 0.38.
(8) The next step was to determine the mean ratio of 5-minutes to 24-hour ratio to 12- to 24-hour in each of the four regions.
(9) The figure 4-72 was developed using ESRI "Spatial Analyst" commands.
(10) Region A has the most intense rainfall distribution because ratios in figure 4D–1 are higher. Region D has the least intense rainfall distribution.
(11) WinTR–20 both smooths the rainfall data and develops a rainfall distribution with ratio data such as contained in figure 4-72. In order to do this, a NOAA Atlas 14 text file at any random location can be edited to include one column in figure 4-72. Since the data are non-dimensional, they may be multiplied by 10 (or any other number) and entered in the NOAA Atlas 14 text file. The number 10 is practical because the 5-minute to 24-hour ratio of 0.143 becomes 1.43 and the ratio for the 24-hour rainfall becomes 10.00. The ratios are treated as rainfall in units of inches.
(12) The WinTR–20 NOAA Atlas 14 smoothing output file shows to what degree the original ratios are non-smooth. WinTR–20 develops a 24-hour rainfall distribution at a time interval of 0.1 hours. The rainfall distributions for region A (most intense rainfall distribution) and region D (least intense rainfall distribution) are plotted for comparison against the NRCS Types II and III in figure 4-73. The region A distribution is slightly more intense than the NRCS Type II and the region D distribution is slightly less intense than the NRCS Type III.

Figure 4-71: NOAA Atlas 14 Volume 2 Region, Rainfall Distribution Regions

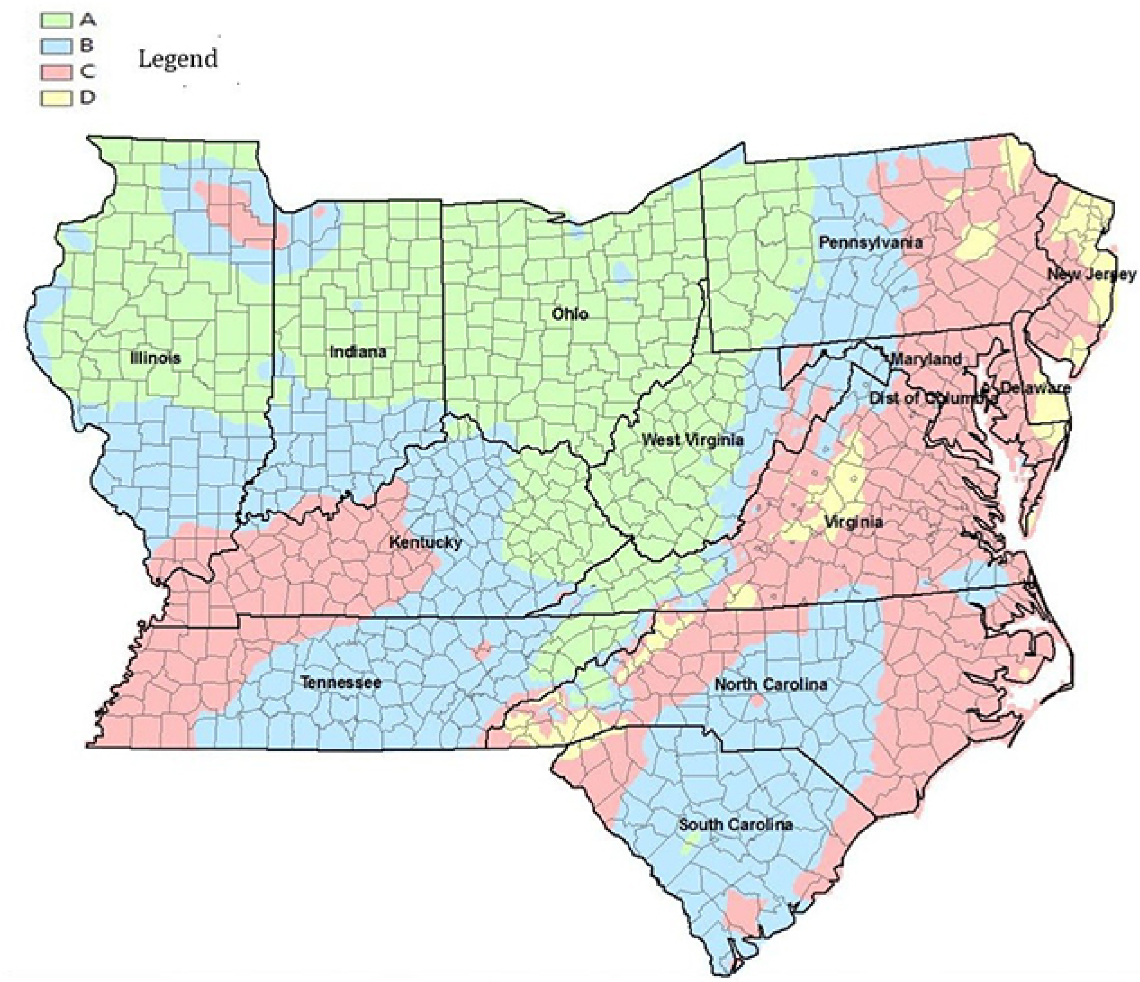
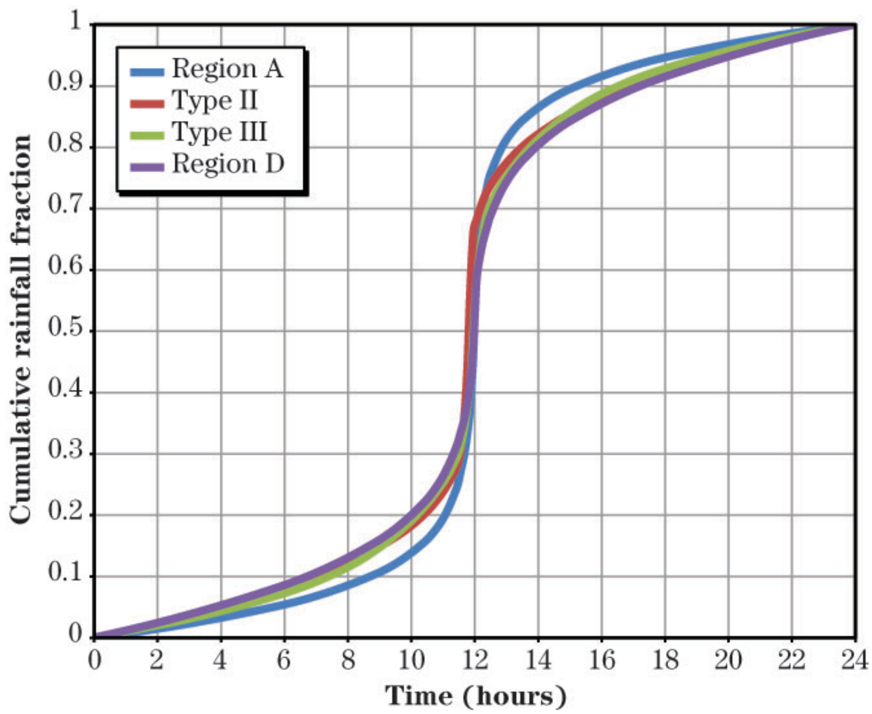


Figure 4-72: Mean Ratios for Four Rainfall Distribution Regions NOAA Atlas 14, Ohio Valley and Neighboring States

Duration ratio	Region A	Region B	Region C	Region D
5-min / 24-hr	0.143	0.121	0.105	0.094
10-min / 24-hr	0.219	0.189	0.166	0.149
15-min / 24-hr	0.272	0.237	0.210	0.188
30-min / 24-hr	0.386	0.344	0.308	0.276
60-min / 24-hr	0.502	0.453	0.409	0.366
120-min / 24-hr	0.594	0.543	0.500	0.454
3-hr / 24-hr	0.635	0.585	0.545	0.501
6-hr / 24-hr	0.749	0.705	0.672	0.636
12-hr / 24-hr	0.864	0.840	0.823	0.805

Figure 4-73: Plot of NOAA Atlas 14 Regions A and D Rainfall Distributions Compared to Type II and Type III



D. Discussion

(1) These rainfall distributions based on the 25-year return period are the default rainfall distributions, which may be selected and used in EFH-2, WinTR–55, and WinTR-20. A different rainfall distribution, based on the 100-year storm for example, may be used in WinTR–55 or WinTR-20 by importing the downloaded NOAA Atlas 14 .csv file or by entering it as an historical storm distribution table.

(2) The rainfall distribution may be used to compute peak discharges in both WinTR–20 and WinTR–55. To derive peak discharge curves for use in EFH chapter 2, WinTR–20 was run for a range of Ia/P (initial abstraction divided by precipitation) ratios and time of concentration.

(3) There are several options to consider when defining the use of maps such as shown in figure 4-74. One is to publish the maps as is and request the user to determine which rainfall distribution to use based on the project location. The maps were generated by GIS, so specific boundary lines are defined. If a user has access to GIS, the process of determining where the project is situated is relatively simple. Another possible use is to define rainfall distributions along county boundaries. In this case, when a county has two or more rainfall distributions a decision needs to be made which distribution to use. Generally, the dominant one or the most conservative one is selected. However, this could cause some parts of a county to have a larger potential error in peak discharge.

(4) For ease in implementation, it may be helpful to ignore small pockets of different regional distributions that appear. In addition to that, in some regions, NOAA Atlas 14 data have bull's eyes that are caused by either high or low precipitation frequency results at individual rain gages with respect to surrounding rain gages. It becomes difficult to specify exactly where these isolated boundaries are by visible physical attributes on the land (roads, rivers, mountains, county boundaries, etc.). If this is the case, the potential maximum and minimum difference in peak discharge may be determined by setting up tests in hydrologic computer models. For example, different rainfall distributions may be used in hydrologic computer models for various watershed sizes and rainfall depths and results compared.

630.0409 References

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